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BM Retrofit
Final Report

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BM Retrofit - Development and demonstration of holistic retrofitting concepts for biomass-based district heating networks

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BM RETROFIT

Development and demonstration of holistic retrofitting concepts for biomass-based district heating networks

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Executive Summary

At both the national and EU levels, there is broad consensus that the use of renewable energy sources must be further intensified in order to reduce greenhouse gas emissions. Across Europe, targets for emission reduction and energy system transformation have been defined within frameworks such as the European Green Deal and the “Fit für 55” package. Achieving these goals requires particular attention to the long-term planning and sustainability of heat supply systems.

In Austria, approximately half of total final energy consumption is used for heating purposes, including space heating and cooling, domestic hot water, and process heat. In 2023/24, around 40 percent of total heat demand was covered by renewable sources. In the district heating sector, the renewable share amounts to roughly 50 percent, primarily supplied by biomass. Beyond climate considerations, current geopolitical and energy policy developments underscore the urgency of reducing dependence on fuel imports and fossil energy carriers. Rapid and comprehensive diversification and defossilisation of the heating sector therefore constitute a central challenge. In addition to appropriate policy and regulatory frameworks, targeted projects operating between research and demonstration such as “BM Retrofit” are essential to support this transition.

<u>The role of biomass-based district heating networks in Austria</u>

While 50 to 70 years ago urban heat supply in Austria was largely based on fossil fuels and fossil-fired CHP plants, rural regions began implementing local district heating networks based on solid biomass from around 1990 onwards. Currently, approximately 2,500 biomass-based district heating plants and around 150 biomass CHP plants are in operation across Austria. Oil and/or natural gas boilers are typically used for peak load coverage and backup purposes. Biomass-based district heating networks thus represent an efficient and flexible pillar of the energy transition.

However, older district heating networks in particular face increasing needs for retrofitting and modernisation to meet current and future technical, economic, and regulatory requirements and to enable the sustainable strategic expansion of the DH network. In practice, a systemic and holistic approach within the concept development is often lacking, and measures tend to be implemented in isolation rather than as coordinated packages. As a result, existing optimisation potential frequently remains underutilised.

<u>Research approach and innovation methodology</u>

Within BM Retrofit, a holistic methodological approach was developed, combining technical, organisational, and systemic measures. This integrated strategy enabled existing district heating networks to be adapted and further developed to meet future requirements. The resulting concepts were demonstrated at three pilot sites, so called demonstrators, namely Wald im Pinzgau, Saalfelden and Kreuzstetten and in several specific use-cases. The entire process was accompanied from the identification of site-specific challenges through concept development, detailed planning, and implementation to data monitoring and optimisation.

<u>Core elements of the demonstrators</u>

The technical components and innovative elements (e.g. integration and optimisation of thermal storage systems; implementation of efficiency-enhancing measures such as flue gas condensation units and (absorption) heat pump systems, etc.) incorporated into the holistic concepts were further developed for efficient system integration and tested, validated, and optimised under real operating conditions at the demonstration sites. They serve as model solutions for broader replication.

- Wald im Pinzgau: Utilisation of low-temperature waste heat from a nearby hydropower plant (cooling circuit) via a 250 kW heat pump; installation of a power-to-heat unit to ensure operational redundancy; 30,000-litre buffer storage tank to enhance flexibility and cover load fluctuations.
- Saalfelden: Modernisation of the biomass boiler system; integration of a cascading heat pump concept (3 x 250 kW) into the flue gas condensation process to increase efficiency; innovative control strategy using CO lambda sensors to optimise biomass boiler operation; upgrade of flue gas cleaning (electrostatic precipitator); 150,000-litre buffer storage tank; installation of a new supply line to increase transmission capacity.
- Kreuzstetten: Targeted network densification based on network simulations; modernisation and improvement of boiler control systems; optimisation of buffer storage management to reduce unnecessary load fluctuations; reduction of return temperatures through secondary-side measures; implementation of a new operational and business model to enhance economic performance.

Holistic assessment and accompanying processes

Based on detailed data monitoring, the technical, economic, and environmental impacts of the implemented measures were systematically analysed. Moreover, lifecycle assessments and value chain analyses were conducted to evaluate impacts on greenhouse gas emissions, primary energy consumption, and domestic value creation. An online business model tool as well as scaling scenarios were developed to assess market potential and energy system impacts. These comprehensive evaluations generated valuable insights for further development and transfer to the broader sector of district network-based heat supply.

Stakeholder and actor identification and engagement constituted another key success factor. Active involvement included workshops, information materials, and public events such as open days to present innovations at the demonstration sites. These activities facilitated dialogue between operators and citizens, improved transparency, strengthened public trust, and provided valuable feedback that proved crucial for acceptance.

Summary and outlook

BM Retrofit has demonstrated that large-scale implementations can be realised within comparatively short timeframes. A system-level integrated perspective is as essential as the application of innovative methods, permanently embedded within a long-term development strategy.

The research approach enabled the implementation of intelligent energy systems that enhance overall efficiency and flexibility while reducing emissions. It supports optimal use of locally available energy sources, leverages synergies within existing infrastructure, and establishes future-proof, sustainable, and economically viable systems. The systemic solutions lead to a pioneering role at national and European level in this field, with high replication and scalability potential.

1 Introduction

Within this chapter a brief introduction into the main content and challenges is given and the applied overall methodology is explained. Furthermore, a first indication and the structure of the work is included.

1.1 Content and challenges

Biomass-based district heating systems already make a substantial contribution to sustainable heat supply in Austria and represent an important foundation for the long-term decarbonization of the heating sector. At the same time, many of these systems are entering a new phase of development: a large share of the existing infrastructure was built one or two decades ago and now faces growing pressure to adapt to new technical, economic and regulatory conditions. Against this backdrop, the project addresses a highly relevant transformation challenge: how existing biomass-based district heating networks can be modernized and expanded in a way that is efficient, resilient and aligned with future climate targets.

The project content is therefore centered on the development of holistic retrofit concepts for biomass-based district heating systems. Rather than focusing on isolated technical upgrades, the approach combines multiple dimensions of modernisation into one systemic framework. This includes the optimisation of biomass boiler operation, the integration of thermal storage, the use of advanced control strategies and digital tools, and the improved interaction between heat generation, distribution and consumption. At the same time, the project considers the integration of additional renewable and local heat sources, such as waste heat and heat pumps, as well as broader questions of planning, network development and economic viability. In this way, the project reflects the reality that the future performance of district heating systems depends not on single technologies alone, but on the quality of their overall system integration.

A particular strength of the project lies in its recognition that existing biomass-based district heating systems must now perform under far more complex conditions than when many of them were first built. Heat demand is changing as buildings are renovated and become more energy efficient. At the same time, operators are expected to connect new customers, integrate additional renewable sources and respond to more demanding climate and market requirements. This creates a clear need for retrofit strategies that improve flexibility, reduce operating temperatures, strengthen overall efficiency and enable smarter operation across the entire network.

The challenges identified are both technical and structural. On the technical side, many existing systems are affected by reduced summer heat demand, inefficient part-load operation, elevated system temperatures and limited flexibility options. These conditions can increase fuel consumption, reduce efficiency and place greater stress on key components. The integration of low-temperature or decentralized renewable heat sources also remains difficult in systems that were originally designed around more conventional operating conditions. In addition, while advanced control concepts and model-based optimisation approaches are increasingly discussed in research, they are still only applied in a limited number of demonstrators and are not yet widely established in routine practice.

A further challenge lies in planning and implementation. Currently, there is still no single established method or market-ready tool capable of addressing the full complexity of district heating retrofit processes. Long-term developments such as changing demand structures, energy price scenarios, climate impacts and infrastructure interdependencies are often not considered systematically enough. As a result, retrofit decisions can remain fragmented, short-term and suboptimal. The project responds to this gap by promoting a broader planning perspective that links technical design, system modelling, spatial energy planning and long-term strategic development.

Equally important are the non-technical challenges. Successful transformation depends not only on engineering performance, but also on business models, stakeholder coordination and public acceptance. The project highlights that holistic retrofit concepts, especially those involving new services, stronger system integration and the participation of relevant actors, are still not sufficiently established in the market. This means that the project is innovative not only because of the technologies it addresses, but also because of the way it combines technical modernisation with organisational, economic and societal dimensions of change.

Overall, the project positions retrofit not as a narrow refurbishment task, but as a strategic opportunity to advance existing biomass-based district heating systems toward a new generation of renewable heat infrastructure. Its content is shaped by the ambition to unlock synergies between technology, digitalisation, planning and stakeholder engagement, while its challenges reflect the real complexity of transforming established energy systems. In this sense, the project contributes not only to the modernisation of individual networks, but also to the broader question of how local heat supply can become more climate-friendly, economically robust and future-proof.

1.2 Overall methodology

To address the research needs and to cover the project goals a methodology based on three different pillars was developed (see Figure 1). It is based on technical measures, non-technical measures and systemic approaches. However, this systemic and holistic approach in the development of retrofitting concepts beyond individual technological solutions and the accurate system integration combined with comprehensive involvement of relevant stakeholders including the expansion of services and business models is currently not applied on the market and the available potential is not being fully utilised.

Through this intelligent combination and holistic approach, it was possible to a) adapt and further develop existing biomass-based district heating networks to meet future requirements (e.g. decentralized generation and storage, load changes, different temperature levels, low summer load with increased heat losses, necessary enlargement, etc.), b) achieve corresponding climate goals and c) strengthen economic benefits including local value chain creation.

The technical components and innovative elements within the BM Retrofit concepts (e.g. boiler replacement, boiler operation, expansion of heating units, storage integration and management, installation of secondary abatement technologies and efficiency enhancement measures like flue gas condensation plants, (absorption) heat pump systems, etc.) included in the retrofitting concepts were further developed and optimized for efficient system integration. Due to the systemic approach and methodology applied coupled with demonstration, especially the indicators SRL (from TRL 4 to 6) as well as MRL (from TRL 4 to 7) were raised accordingly. Within the implementation, process support was provided along the entire value chain (from specific concept development to planning, implementation, commissioning, data monitoring and evaluation as well as optimisation).

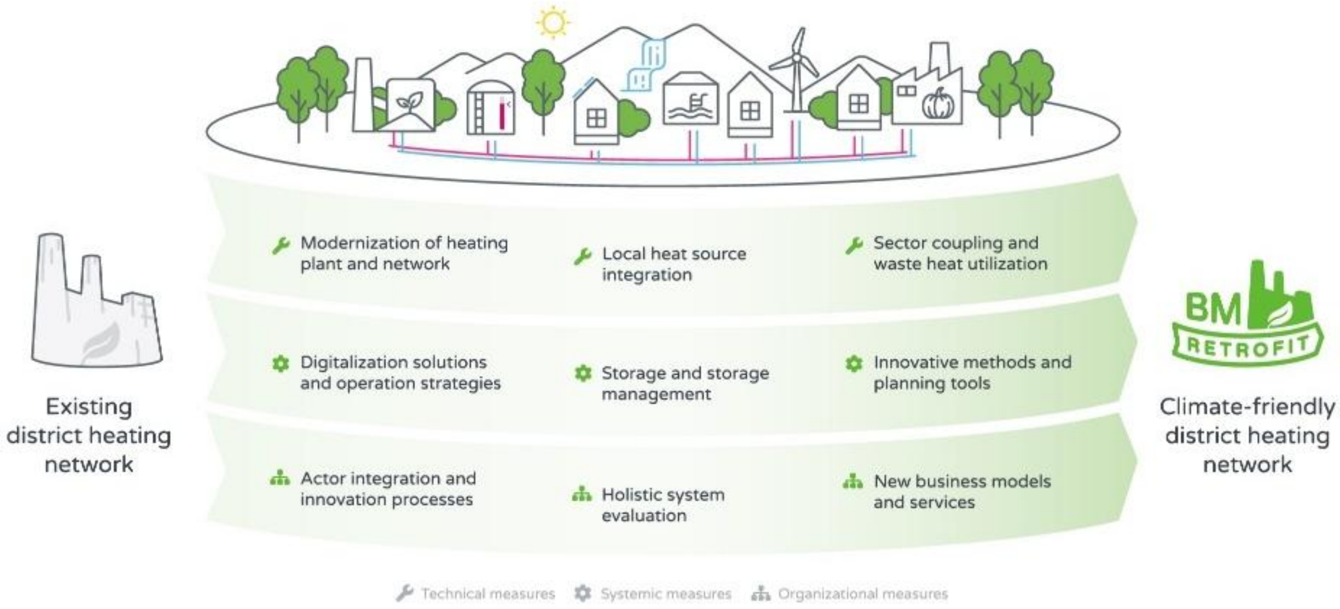


Figure 1: Methodological framework within BM Retrofit, Source: Green Energy Lab

This ensure that innovative measures can be further improved and integrated, resulting in more sustainable and economical operations associated with reduced resources and environmental savings. BM Retrofit enables for the first time the realisation of a sustainable energy system a) with increased overall efficiency and flexibility, b) with the best possible use of renewable and local energy sources, c) with full exploitation of synergies of existing infrastructures, and d) with the creation of a future-proof and resilient system.

1.3 Structure of the work

Within this publication, the outcomes of the BM Retrofit project are described concisely. The publication is structured as follows. First, in Chapter 2, the broad range of retrofitting and modernisation options for the demands of DH operators was summarised. The developed concepts for implementation as well as the gained results from the planning, realisation, monitoring and evaluation phase were summarised in Chapter 3 for the respective linked demonstrators. Chapter 4 includes relevant actor and stakeholder integration aspects including the performed innovation process and Chapter 5 deals with the business model tool as well as scaling scenarios and roll-out potential. Dissemination and exploitation results were given in Chapter 6 while in Chapter 7 the overall conclusions and a brief outlook is given.

2 Retrofitting in the district heating sector

Chapter 2 summarises the range of retrofitting options in the DH sector and for the demands of DH operators. After a short introduction, the biomass-based district heating sector in Austria and the key performance indicators (KPIs) and benchmarking methods are explained. Finally, the evaluated retrofitting measures of the project are summarized.

The district heating sector in Austria can roughly be separated into large-scale systems (e.g. Vienna or Graz), currently heavily relying on fossil energy sources and small to medium-scale networks, typically relying on biomass as the main energy source. Biomass-based district heating networks with typical sizes of up to 10 MW_{th} play a central role in sustainable heat supply, with around 2,500 systems currently in operation. Thus, biomass-based district heating plays a major role as an efficient and flexible solution for the energy transition. BM Retrofit focused on the small- to medium-scale systems based on biomass.

Most of these systems are turning so old that retrofitting and refurbishment measures on component and system level will be necessary in the next years. Next to this need for modernisation of existing systems, boundary conditions for biomass-based DH operators have changed considerably as the integration of other renewable energy sources has to be accelerated to drive decarbonization, new customers with former oil and gas heating have to be connected and supplied, while an increasing number of buildings with low heating demand after renovation are also part of their systems. Therefore, a wide range of changes and developments are necessary for the transition into future sustainable systems with high efficiencies and decreased, nearly zero emissions.

2.1 Biomass-based district heating sector in Austria and benchmarking

To evaluate the status quo of these plants, the publicly accessible Austrian Heatmap (austrian-heatmap.gv.at) was used as a first basis. In addition, the QM database (qm-datenbank.at), in which all subsidised heating plants in Austria are listed by Kommunalkredit Public Consulting, was accessed to get detailed information on the heating plants. These data were cross-referenced with publicly available data from the Austrian Biomass Association, presented in the “Bioenergie Atlas” (see Figure 2). By combining the databases, the status quo of the heating plants was established regarding the integration of currently available modern technologies (heat recovery systems, heat pumps, storage tanks, solar thermal systems).

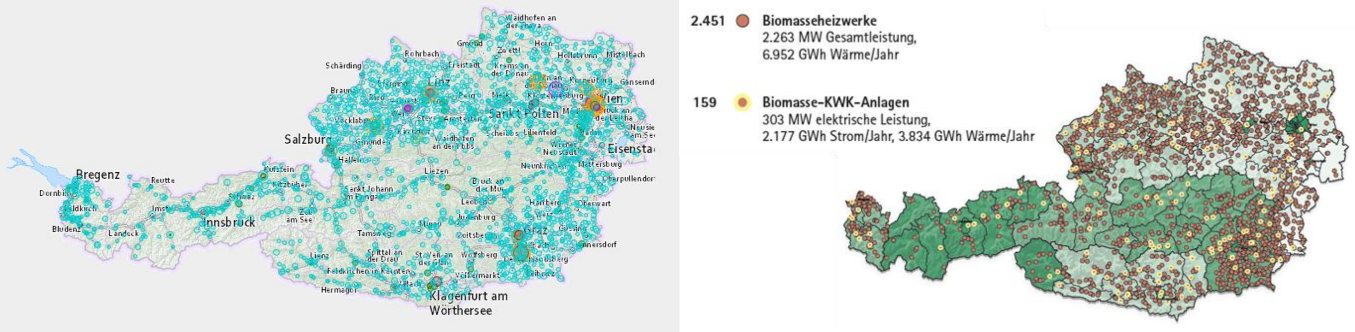
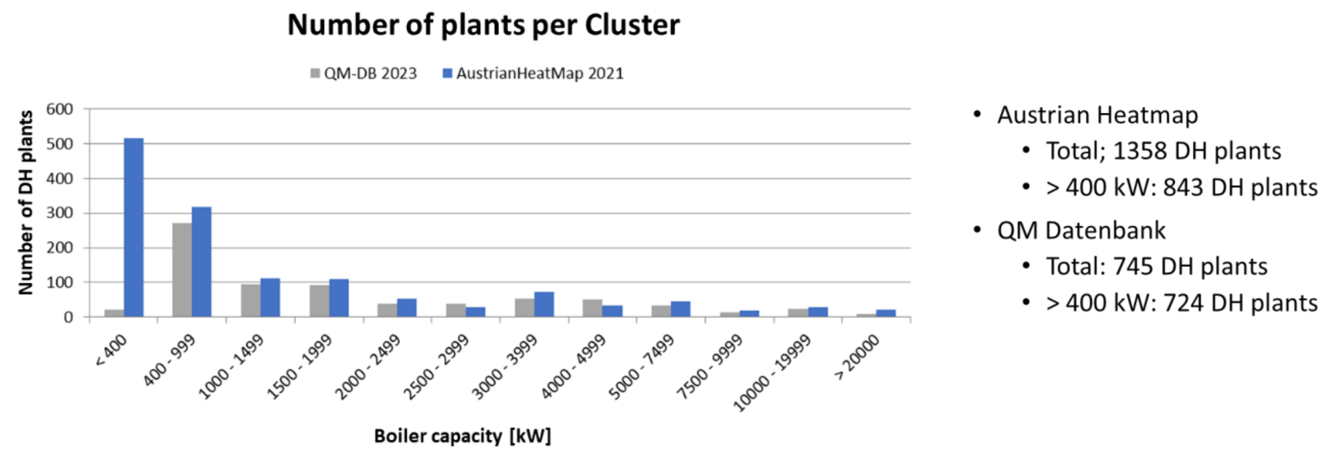


Figure 2: Left side: DH systems in Austria, source: Austrian Heatmap. Right side: Biomass-based DH systems in Austria, source: Bioenergie Atlas 2024, Austrian Biomass Association

A clustering of DH plants by their total biomass boiler capacity, see Figure 3, represents an adequate overview of the situation in Austria in terms of size of the DH system. Clustering was possible for data from the Austrian Heatmap and the QM database where specific data for each plant was available. The QM database mostly contains plants that are required to use the QM system. Until 2024, this applied to plants with a nominal boiler capacity larger than 400 kW. Hence, only few plants (on a voluntary basis) below 400 kW are contained in this database. The modernisation concepts developed within BM Retrofit are aimed at DH plants larger than these 400 kW, all plants below this capacity were not considered within the project. The comparison shows that about 840 plants of this minimum size are in operation and that this limit therefore represents a significant share of biomass-based DH networks with a reasonable optimisation potential.

Clustering according to boiler capacity is on the one hand relevant, since the capacity is the main criteria for regulatory aspects such as the Feuerungsanlagenverordnung (FAV) or the Renewable Energy Directive (RED) and hence influences regulatory boundary conditions for these plants. On the other hand, the market potential for certain modernisation options developed within BM Retrofit depends on the capacity since not all options are applicable for all plants, either due to technical or economical constraints.



- Austrian Heatmap
  - Total; 1358 DH plants
  - > 400 kW: 843 DH plants
- QM Datenbank
  - Total: 745 DH plants
  - > 400 kW: 724 DH plants

Figure 3: Clustering of DH systems according to their total boiler capacity. Systems below 400 kW were not required to be registered in the QM database and are thus underrepresented in this lower cluster.

For these systems, the already installed technical components that enhance the efficiency and operation behaviour of a biomass-based DH system were evaluated and also clustered relative to the plant size. The evaluation shows that heat storage systems are widely used independent of the boiler capacity (in total in 71% of all plants), but heat recovery systems such as flue gas condensation units are primarily employed in plants above 1.500 kW compared. Solar thermal collectors are mainly found at smaller plants below 1.000 kW but are generally scarcely used as well as heat pumps. Hence, the status quo shows that there is considerable potential for modernisation and efficiency improvement with already available technologies.

Within BM Retrofit an Excel based benchmarking tool, the "*BM Retrofit Anlagencheck*" including most relevant key performance indicators (KPIs) was developed and allows a qualitative comparison to other DH plants (e.g., data of the *klimaaktiv* programme "*Heizwerke und Wärmenetze*", formerly *klimaaktiv QM*

Heizwerke). Furthermore, it allows the collection of relevant data from plant operators in a simple way and provides a quick possibility to examine and evaluate the DH plants regarding their performance as well as to identify their modernisation requirements. Within BM Retrofit, the system was primarily used to assess the three demonstrators. In addition, potential use cases were analysed to assess their suitability in BM Retrofit. An evaluation of KPIs was undertaken and for example the total energy efficiency, the full load operating hours of the biomass boiler, the mean temperature spread (between feed and return temperature) and the losses in the DH network were identified.

2.2 Evaluation of potential retrofitting measures

Retrofitting measures include several aspects that are relevant for the modernisation of biomass-based district heating systems. These include:

- Technical components and system solutions
- Planning and simulation tools
- Measurement and control concepts
- Storage technologies and storage management
- Operation control strategies and merit orders

2.2.1 Technical components and system solutions

The evaluation of suitable technical components for biomass DH plants focused on heat recovery processes that allow a significant increase in the efficiency of the plants. Especially *active flue gas condensation* in combination with *heat pump technologies* (compression and absorption) was identified as a key technology to transform existing heating plants into high-efficiency heating plants (an increase of 30% and more of heat production compared to systems without heat recovery). In view of the limited resources of locally available biomass, a maximum utilisation of the fuel is essential to ensure a sustainable, renewable energy supply with biomass. As shown in section 2.1, this technology is not yet widely used and offers a high potential to increase the heat supply via biomass-based district heating without additional biomass consumption.

System solutions in the context of BM Retrofit focus on heat supply in addition to the biomass boiler. Solar thermal plants and heat pumps were identified as the most relevant solutions. Both technologies are suitable to supply heat to the DH system a) in addition to a biomass boiler to increase the total heat supply and b) instead of a biomass boiler at times of low heat demand. Especially during the summer period, where domestic heating systems are not active and mainly hot water preparation is required, solar thermal plants and heat pumps can cover the full load of the DH system and biomass boilers can be entirely shut off. This allows to avoid stop-and-go operation of the biomass boiler which typically causes high gaseous and particulate emissions due to incomplete combustion.

2.2.2 Planning and simulation tools

Spatial energy planning (SEP) was analysed as a method to be applied within the modernisation process of biomass-based DH plants. SEP coordinates the energy supply with the structural development of a community. It serves for analysis and communication, making energy infrastructure (buildings, networked infrastructure, renewable potentials) as well as priority, suitability, and restriction areas for renewable energy potentials (zonings) visible. It also supports planning purposes as a basis for planning services (district heating strategy, settlement/area development, etc.), scenario analyses (existing transformation), and energy and ecological balancing. Within BM Retrofit SEP was used to develop DH extension scenarios for all demonstration cases.

To improve the heat demand modelling used within SEP, a master thesis focusing on the "utilisation of satellite data for the improvement of spatial heat demand modelling" was carried out within BM Retrofit at AEE INTEC. The method developed allows the identification of not known heated buildings, which can be possible customers or sources for waste heat. The most promising aspect related to district heating is the identification of possible waste heat sources, e.g. from industrial processes, that can be utilized in the DH system.

For thermohydraulic simulations different tools and software solutions (e.g. simplex, Dymola, Stanet) were evaluated. For example, Simplex allows a detailed simulation of the DH network including the heat producers, the network itself and the customers. Based on the simulation, the state of the network (temperature load, pressure load, bottlenecks) is determined. This allows variant calculations to determine if additional heat sources and/or additional customers can be implemented or if additional pipework (including ring pipes) is needed.

2.2.3 Measurement and control concepts

BM Retrofit assessed enhancement opportunities for medium-sized biomass boilers in local heating grids, focusing on control and monitoring concepts. Standard control typically involves four PID-control loops: negative pressure inside the combustion chamber, oxygen content in the flue gas, combustion temperature, and thermal power control. Each loop serves a specific purpose, such as maintaining pressure, ensuring complete combustion, controlling temperature, and regulating thermal output. Practical implementation and compatibility with existing systems are prioritized in evaluating retrofitting measures. The suggested retrofitting concept extends standard control, notably through CO-lambda optimisation for flue gas oxygen content control. CO-lambda optimisation involves setting an optimal oxygen setpoint to minimize CO emissions while maximizing efficiency. However, its adoption requires specific boiler properties not fulfilled by all biomass boilers, such as flue gas recirculation and independent control loop adjustments. These requirements are outlined in a factsheet sent to Austrian plants to evaluate the retrofit potential.

While negative-pressure control is effective and lacks significant retrofitting potential, combustion temperature control typically works well if plant components are properly sized and flue gas recirculation is installed. Thermal power control presents significant retrofitting potential, particularly concerning system-level aspects including power and storage management.

2.2.4 Storage technologies and storage management

Storage technologies suitable for DH systems were evaluated regarding their suitability for biomass-based DH systems. Above-ground tank storages using water as their storage medium are typically used for that application. They are either integrated into the boiler house or erected outside the boiler house. The predominant use of storage systems is for peak load management. Hereby a constant operation of the biomass boilers without drastic load changes is reached and the need for oil and/or natural gas-fired peak-load boilers is reduced. It ensures low emission levels, low system wear and resulting low maintenance costs as well as a long service life of the biomass boiler. For an optimum operation of the storage the correct dimensioning of the storage volume is crucial. In addition, a minimum of 5 temperature sensors is needed to enable a correct detection and control of the storage tank's state of charge.

A well-designed storage management system is needed to ensure supply security by avoiding failures, improve boiler operation conditions and minimize the use of peak load boilers. The storage management directly or indirectly dictates several key aspects:

Firstly, it determines the amount of energy that needs to be reserved and at which temperature. For instance, it ensures that in the event of a boiler failure, there is enough energy to bridge the gap for a certain period, such as one hour, required to either fix the issue or start up a backup boiler. Secondly, it specifies the charging and discharging power of the storage units. Typically, this is done indirectly, where a low-level controller manages the boiler, and the charging power corresponds to the difference between production and consumption. Consumption is regulated by the differential pressure control of the network pump, the feed temperature and the demand from the transfer stations. However, with decentralized storage, charging and discharging power may be directly controlled, such as through power regulation of network pumps, while differential pressure maintenance occurs at a central point. Lastly, it determines how energy or power should be distributed among different storage units. For instance, at a single site, this could involve serial charging (if not mechanically predetermined) versus parallel charging. For example, lower temperature energy from solar thermal sources could be directed into one storage unit, while higher temperature energy from boilers could be directed into another.

2.2.5 Operation control strategies and merit orders

One the one hand, low-level control strategies focus on aspects such as oxygen levels, temperatures, and power output, while high-level controllers manage tasks such as boiler activation, power modulation, storage management, and coordination with other energy sectors. Additionally, they can influence customer demand indirectly or directly.

Retrofitting in high-level control involves implementing better control strategies, termed as Energy Management Systems (EMS), either on existing SCADA systems or through add-on solutions. These can be simple rule-based strategies implementing a certain order of heat producers (merit order), e.g., due to different buffer temperature levels for switching components on or off. Such rule-based strategies are the de-facto standard but require some sophistication and trial-error to guarantee good operating conditions under varying boundary conditions. The same rules that provide good performance in winter might lead to unacceptable behaviour in summer.

More advanced concepts incorporate predictions of heat demand and yield from renewable sources such as solar thermal or waste heat. This often results in rather complicated rules, making it difficult to account for all eventualities.

Finally, optimisation-based approaches naturally handle predictions and varying boundary conditions as, for example experienced with systems involving Combined Heat and Power (CHP) units which participate in the electricity market. However, they require sufficiently accurate mathematical models to describe the available components, they require hardware with sufficient computational power, and lead to optimized schedules that cannot be easily interpreted or adjusted if incorrect. Therefore, it is recommended to integrate optimisation first as a decision support measure, and only advance to direct control once sufficient acceptance and trust has been built up.

An existing framework for optimal control of heating networks has been developed further in this project, with special attention to two demonstrators handled in this project. Rule-based control adjustments were investigated for and implemented in Kreuzstetten, while the potential of optimal control strategies were evaluated in simulation studies both for Kreuzstetten and the more complicated Wald im Pinzgau.

3 Demonstration sites and solution approaches

In this chapter, the developed and subsequently realised retrofitting measures for the addressed demonstration sites (demonstrators) are described in detail. The results of the planning, realisation, monitoring and evaluation are summarised for each demonstration case. Possible roll-out scenarios and their market potential are summarised later in Chapter 5.

The map of the demonstrators is illustrated in Figure 4. BM Retrofit utilised three demonstrator sites (Wald im Pinzgau, Saalfelden, Kreuzstetten) to showcase, validate, and optimise the developed retrofitting concepts, and drew on these experiences to derive best practices. Within detailed data and system evaluation and validation, the technical, economic and ecological benefits and impacts of the realised retrofitting and modernisation measures within the demonstrators were investigated.

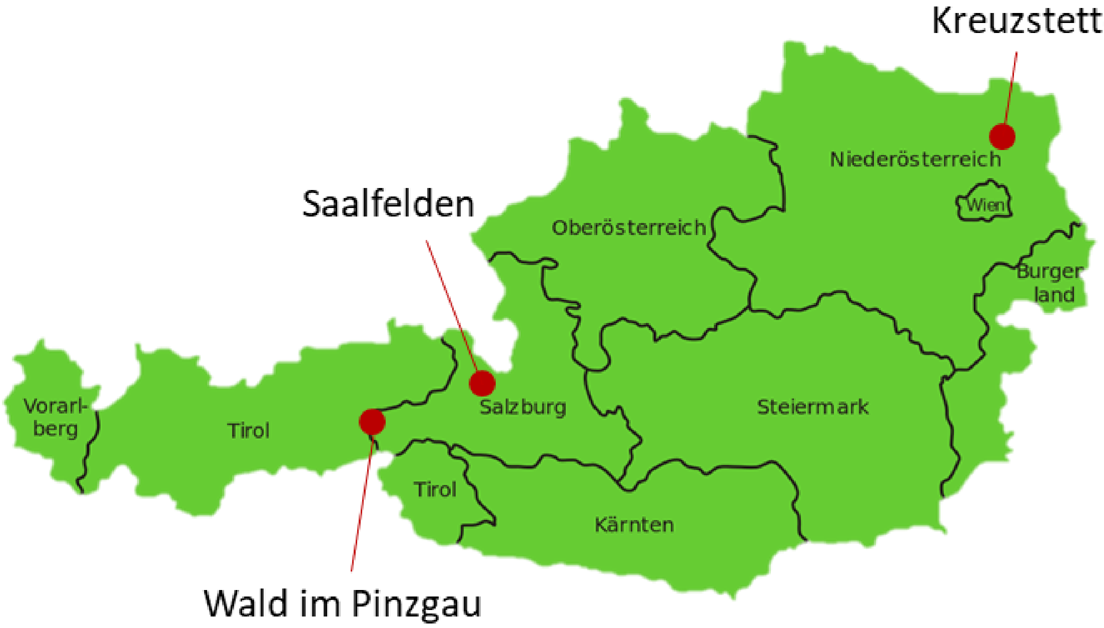


Figure 4: Location of the three demonstrator sites. Source: AEE INTEC

In the following, the main realised measures at the demonstration sites are summarised briefly:

<u>Wald im Pinzgau</u>: Integration of a 250 kW heat pump to utilise low-temperature waste heat from a nearby hydropower plant (cooling cycle); power-to-heat unit to ensure operational redundancy and support feed temperature adjustments; 30,000-litre thermal storage tank to increase flexibility and cover load fluctuations.

<u>Saalfelden</u>: Technical modernisation of the biomass boiler system, including a flue gas condensation system; integration of a cascading heat pump concept (3 x 250 kW) into the flue gas condensation to further increase the efficiency; innovative control strategy using CO lambda sensors to optimise biomass boiler operation; buffer storage tank with a volume of 150,000 litres.

<u>Kreuzstetten</u>: Technical optimisation of the biomass heating plant to overcome current challenges (e.g. insufficient summer operation, elevated system temperatures); targeted network densification based on simulation and spatial energy planning; improvement of boiler control and buffer storage management to reduce unnecessary load fluctuations; new business model.

3.1 Methodology applied

The overall methodology based on three different pillars, as presented in section 1.2, and consists of technical measures, non-technical measures and systemic approaches. To complete the implementations as well as scientific monitoring concepts successfully and ensure an efficient and effective operation of the demonstrators and appropriate data for later evaluation, different methods were applied. Within this section, the methods used are briefly summarised:

Status quo evaluation: An assessment of the status quo of the plant operation as well as an identification of modernisation requirements or retrofitting concepts was performed using the "BM Retrofit Anlagencheck". The process is described in more detail in section 2.1.

Retrofitting concepts: To transfer the findings and results of the status quo evaluation and to select the most suitable concepts to meet the local boundary conditions of the demonstration sites (the measures themselves are summarised in detail in section 2.2.), further concept developments based on simulations, planning and evaluation methods were completed and demonstrator-specific concepts were developed.

Monitoring: To monitor, analyse and evaluate the operational data, monitoring concepts for each demonstrator were developed. For all demonstrators, the monitoring concepts focused on collecting data on each heat generation unit, the heat storage system, the system load management and the district heating network. In addition, data relevant for the specific technical retrofitting concepts and KPI´s were collected and evaluated (e.g. heat pump operation in Wald im Pinzgau).

System evaluation and optimisation: The monitoring concepts provided the basis for further optimisation as well as to process and prepare the monitoring data for system evaluation. Besides the technical evaluation performed within the monitoring of each demonstrator, the solutions implemented were also evaluated over their whole life cycle as well as regarding their economic impact on the economy. Since these methods are not described in the technical section of retrofitting measures (chapter 2.2), they are elaborated in detail at this point:

Life Cycle Assessment: The main objective of Life Cycle Assessment was to compare the Global Warming Potential (GWP) and the Cumulated Energy Demand (CED) of the demonstrators before and after the implementation of BM Retrofit measures, including also some intermediate years of operation to show the impacts of BM Retrofit implementation phases. LCA work is based on the ISO 14040 standard (ISO 2006) and is structured in four consecutive stages: (i) goal and scope definition, including a clear description of the function of each of the three demonstrator systems and its boundaries. The so-called functional unit as base for comparison in BM Retrofit is the yearly heat demand of the district heat customers; (ii) life cycle inventory, which is the compilation of all foreground and background data related to each demonstrator and scenario. Foreground data were collected from monitoring or simulated data of the demonstrators, the source of background data are the LCA database ecoinvent V3.11 and scientific literature; (iii) life cycle impact assessment, in which the full inventory of inputs and outputs is translated into metrics of environmental impact, in this project the GWP (in t CO2e/year and t CO2e/MWh heat demand) and the CED (in MWh/year and MWh per MWh heat demand); and (iv) interpretation, in which results are discussed and interpreted in relation to project objectives.

LCA of the demo sites considers the impact of the installation and end-of-Life treatment of the technical system as well as impacts from the operating phase. Foreground data related to the technical components were collected from technical data sheets and literature of technology providers. GWP and CED of installed technical systems are equally distributed to the years of operation by their expected lifetime. Foreground data from operation comprise yearly energy balances of heat supplied to the district heat (DH) customers, including all conversion losses from primary energy carriers supplied to the heating plant to the transport of heat in the DH grid. For Saalfelden and Kreuzstetten, where additional households were connected to the DH grid as a consequence of BM Retrofit measures, an energy-supply-mix of those households before grid connection was assumed. For all systems operated with electricity, such as heat pumps or power-to-heat-systems, two electricity scenario were assumed, based on 100% renewable supply and on the physical electricity mix in the national grid, including imported electricity.

Value Chain Analysis: The impact analysis on value chains was performed based on GLOB-IO, an environmental extended multiregional input-output macroeconomic model for the global economy. The model reflects the structure of the global production system including the demand for intermediary inputs at all stages and allows to analyse direct, indirect and induced economic impacts. The model is based on OECD input-output tables and covers 77 different countries/regions and 45 different economic sectors. The aim of the model is to analyse how the production of one sector serves as an input for other sectors (and for itself). It aims to calculate the total output required to satisfy a specific final demand, such as household consumption, government spending, or exports. The model rests on the "Leontief Production Function," which assumes that inputs are used in fixed proportions to the output with constant returns to scale. In addition to the direct effects associated with an economic activity, indirect and induced economic effects can thus be derived, where indirect effects arise from companies' demand for intermediate goods and induced effects are generated by positive or negative income effects as households adjust their consumption to changing income levels. The model allows for the analysis of the impact of economic shocks along global value chains and their consequences for key socioeconomic indicators. For the economic evaluation GLOB-IO has been updated to the 2025ed of the OECD Input-Output-Tables. For the analysis 2019 as base year was selected, because all succeeding years are influenced by the COVID crisis.

The evaluation of the demo sites considers the impact of the investment phase and impacts during the operating phase. Input data on the investment was collected from the project partners. For the operating phase the evaluation draws on monitoring data which was collected during the project. The analysis was performed at constant prices with 2025 as price base. Direct yearly effects of investment and operation haven been derived including financing costs for the expected lifetime. For Saalfelden and Kreuzstetten, where additional households have been integrated in the district heating, hypothetical costs of households for the reference system have been estimated. These include energy costs, maintenance costs and reinvestment costs an individual heating system. Additionally, the gain in floor space through the replacement of the heating system with a transfer station was taken into account as half of the average rental price per m2. The assessment focussed on the impact on value added and employment of the demonstrators in comparison to defined reference system.

3.2 District heating network Wald im Pinzgau

3.2.1 Description and realised concept

The DH plant in Wald im Pinzgau supplies about 60 customers via a local heating network with a thermal load of around 1.8 MW. The annual heat demand amounts to more than 3 GWh. Before retrofitting measures, heat was generated by a biomass boiler with a thermal capacity of 0.9 MW and an oil-fired boiler with a thermal capacity of 1.5 MW. However, this system was facing several operational challenges. In particular, the low heat demand during the summer months results in comparatively high network losses. At the same time, the biomass boiler did not operate efficiently under all load conditions, which was reflected in increased maintenance requirements and costs. Another weakness of the existing system was its limited flexibility, as no measures such as thermal storage are currently in place to better balance heat generation and demand.

Figure 5: DH plant in Wald im Pinzgau. Source: Salzburg AG

Based on the findings from the status quo analysis a multi-phase methodology was developed. In the first retrofitting phase (phase 1), an innovative combination of technologies with sector coupling for waste heat utilization using a compression heat pump was developed. In general, heat pump technologies offer great potential for integration in biomass-based DH systems. One of the main characteristics is their ability to make use of low-temperature heat to supply heat at a higher temperature level by electricity (compression heat pumps). Waste heat from the cooling cycle of a nearby hydropower plant is used by an innovative heat pump concept (250 kW_{th}), which is operated with renewable electric power directly produced on-site from the hydropower plant. The heat pump is combined with a 180 kW_{th} Power-to-Heat unit, which serves as a backup in the event that no waste heat from hydropower plant is available. In addition, in increased the flexibility of the system, since it is used to raise the temperature after the heat pump during peak demand periods. An appropriate redesign of the (process) control and measurement systems was developed accordingly.

Figure 6 shows a schematic diagram of the heat pump with indicative temperature levels on the heat source (cooling cycle of the hydropower plant) and a supply temperature in the range of 78°C at the heat sink (DH network).

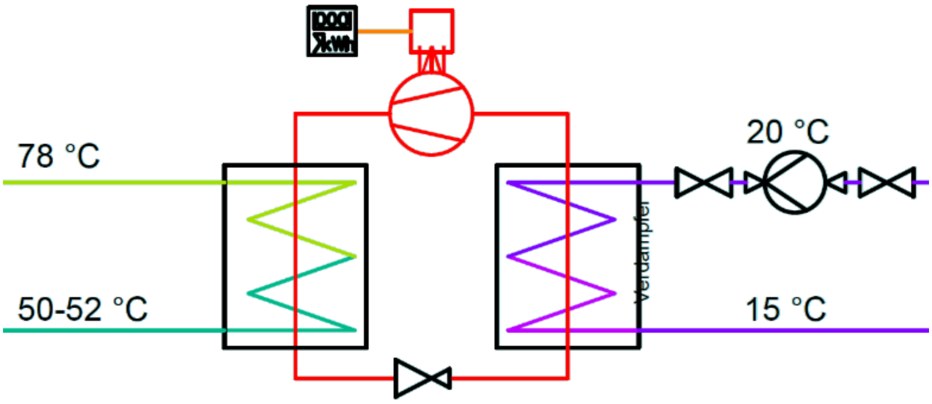


Figure 6: Schematic of the heat pump for hydropower plant waste heat utilization. Source: Salzburg AG

To gain more flexibility and secure efficient operation of the heat pump as well as of biomass boiler, a concept for a heat storage (30 m³) and a proper storage management including linked adaptions on the current process control system and visualization was developed and realised. Figure 7 shows the realised heat storage and the heat pump in the boiler house.

Figure 7: Left: DH plant with the 30 m³ heat storage. Right: 250 kW$_{th}$ theat pump installed in the boiler house. Source: Klimafonds / Krobath

3.2.2 Data analysis and monitoring

A detailed monitoring concept was developed to collect data on each heat generation unit, the heat storage system, the system load management and the district heating network. On the one hand, this data-driven approach ensured that any necessary adjustments can be made to optimize performance. On the other hand, these data allow a detailed evaluation of the impact of the modernisation concepts realised.

The overall objective of the heat pump integration was to enable fossil-free summer operation. The system went into operation in July 2024, and during the heating season 2024/2025 a full monitoring was possible. Heat supply in the heating season 2024/2025 was primarily covered by the biomass boiler, while the newly installed buffer storage significantly reduced the need for oil boiler operation. From May 2025 onwards, the biomass boiler was shut down for summer operation, and heat supply was shifted to the heat pump and the electric heater. Initial operational issues with the heat pump in May and June 2025 temporarily required oil boiler support. From July 2025 onwards, stable operation was achieved, and the network was supplied as planned by the heat pump and P2H system.

On an annual basis, the combined heat pump and P2H system already contributed 18.8% of total heat generation in 2025. Oil consumption was reduced from 210 MWh to 140 MWh, with the potential for near-complete elimination under fully stable operation. Biomass use decreased from 3,610 MWh to 2,950 MWh due to the summer shutdown of the boiler, thus preventing inefficient operation of the boiler at low partial load during summer and reducing the wear-and-tear and thus maintenance costs. Overall heat demand remained approximately constant between 2022 and 2025 (see Figure 8).

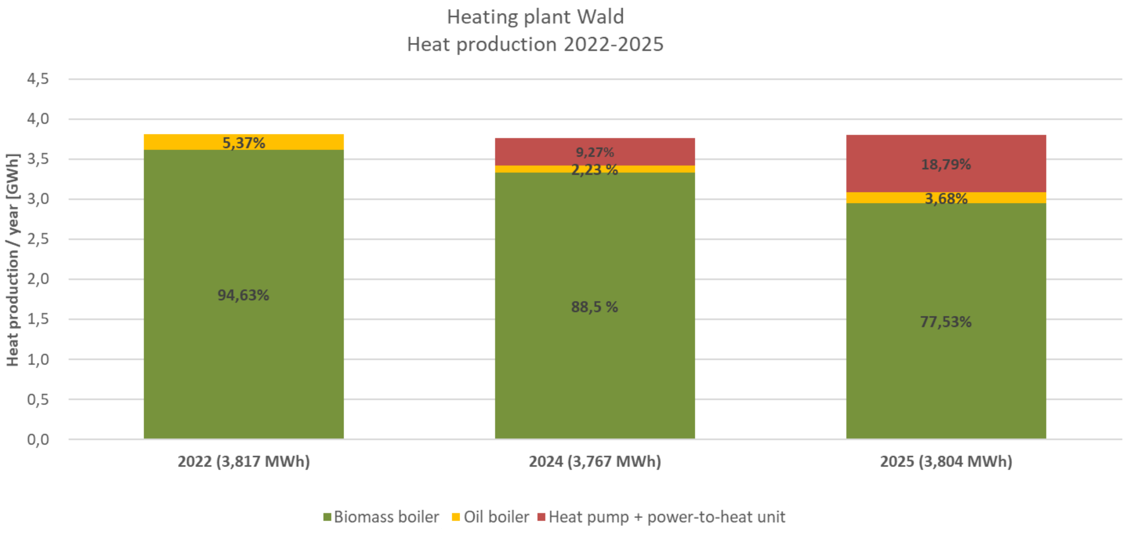


Figure 8: Development of yearly heat production and share of energy sources

Monitoring data of the heat pump system showed that the available heat source temperature from the hydropower plant was approximately 20°C during the analysed summer period. Once stable operation was established, the heat pump provided an average thermal output of 197 kW during operating hours. Due to the daily storage operation of the hydropower plant, continuous waste heat availability was not guaranteed, highlighting the importance of the P2H unit for ensuring constant supply temperatures.

3.2.3 System evaluation and optimisation potential

Life Cycle Assessment

For the demo Wald im Pinzgau the evaluation is based on a comparison of the reference year 2022 before BM Retrofit and 2025 after implementation of measures within the project. For 2025 a scenario with an optimized heating pump integration was considered, resulting in a phase-out of oil boiler operation. The results show a decrease of the GWP by 45% and of the CED by 15%. The decrease of the GWP is due to the phase-out of oil boiler operation which largely compensates the additional GWP due to the installation of the heat pump, the power-to-heat system and the heat storage. The decrease of the CED is due to the higher system efficiency with optimized heat pump operation.

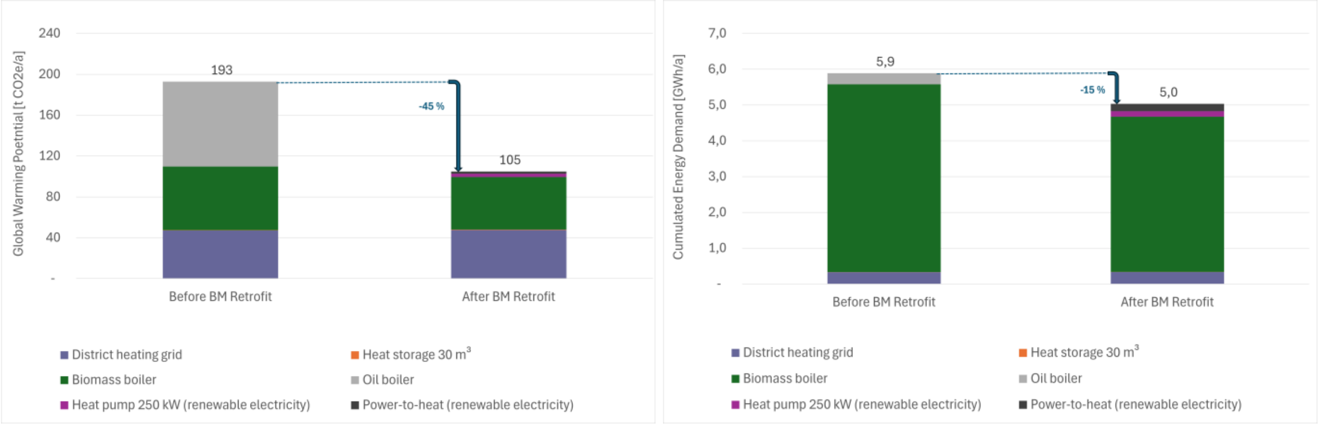


Figure 9: Yearly GWP and CED of the demo Wald im Pinzgau

Value Chain Analysis

For Wald im Pinzgau the evaluation is based on a comparison of the year 2022 as reference with 2024 and 2025 after the adaptions within the project. For 2025 a scenario with an optimized heating pump integration was considered. In 2023 around €790.000 has been invested for the integration of a heat pump, thermohydraulics, electrical installations and planning. The ratio between CO2 reduction and investment shows that for every €1,000 invested, approximately 12 kg of CO2 are saved annually over the investment's lifespan.

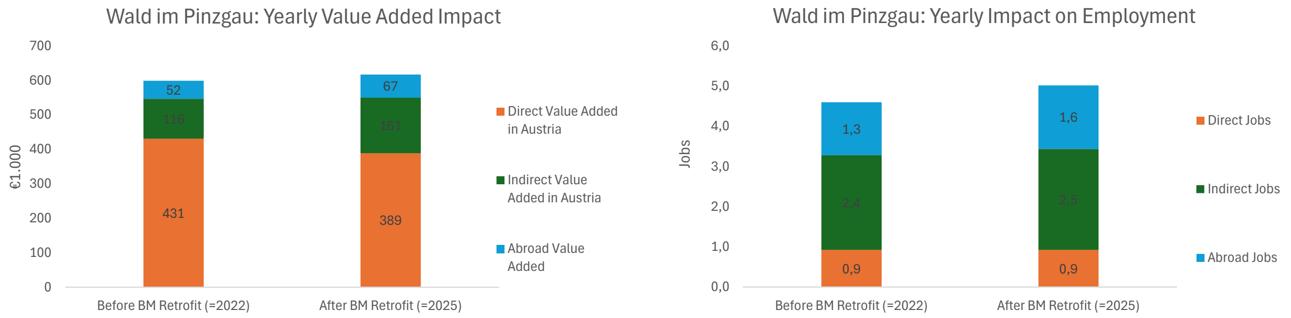


Figure 10: Yearly economic impacts of the demo Wald im Pinzgau

The measures implemented in Wald im Pinzgau have led to an increase in annual value added in Austria of approximately €3,000. However, annual direct value added has decreased by approximately €42,000. This is primarily due to higher energy costs. Overall, there is a marginally positive effect on employment, with the majority of the effect attributable to foreign countries.

For Wald im Pinzgau only electricity costs excluding grid costs of €120.0 has been considered. The price of biomass was set to €25.0 per MWh and oil to €83,5 € per MWh. The COP of installed heat pumps is relatively low, resulting in the negative effects on the direct value added.

Predictive Control Strategy

The predictive control strategy for the energy system in Wald im Pinzgau aimed to enhance the efficiency and cost-effectiveness of heat supply by optimally coordinating the biomass boiler, heat pump (HP), and P2H unit. The system dynamically adapts to electricity prices, waste heat availability, and heat demand to reduce costs and extend the lifespan of the components. The heat pump can only be operated when waste heat from the hydropower plant's turbine is available. Additionally, the buffer storage must still have capacity, and operation must be economically viable—particularly during periods of low electricity prices. However, as waste heat is not continuously available, the heat pump's utilization remains limited mainly to spring and summer.

In summer a simulation study compared operation of the predictive control strategy with historic data of 3 months operation. Here the unit commitment of the heat pump, the P2H unit and the oil boiler was solved by numerical optimisation to minimize the economic costs. This evaluation showed that the predictive control strategy uses the heat pump more often and utilizes flexible electricity prices to reduce the costs by 29%, see Figure 11.

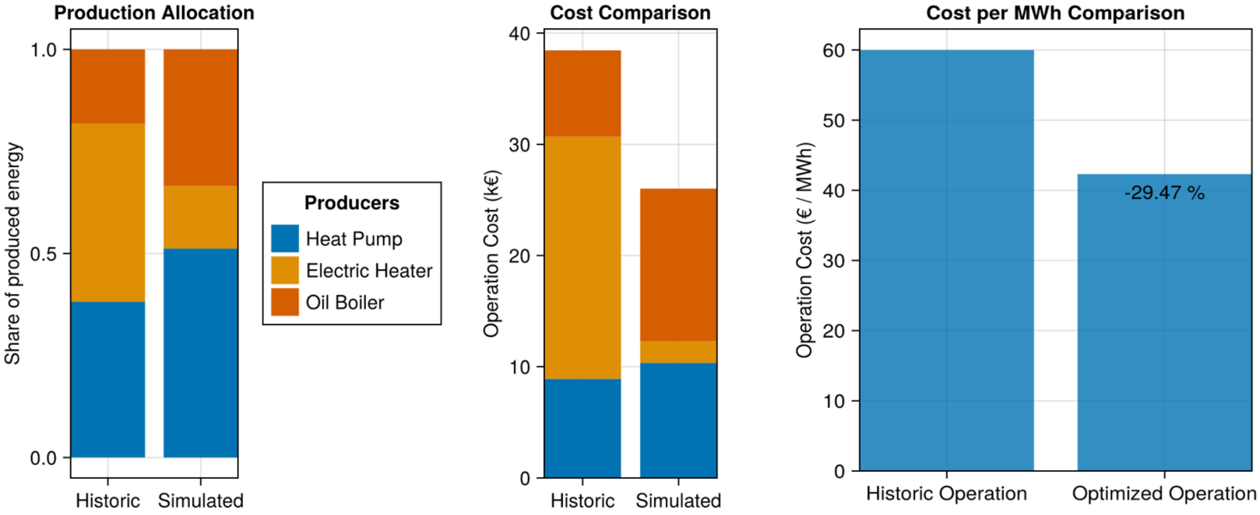


Figure 11: Evaluation of a simulation study for the predictive control of Wald im Pinzgau during summer. Source: BEST.

In the transition periods the biomass boiler plays a central role by replacing the heat pump and/or P2H unit during high electricity prices or insufficient waste heat availability. To avoid frequent start-stop cycles, which strain the boiler, the predictive control system ensures that the boiler adheres to minimum runtime requirements. This is achieved through forecasting heat demand and available storage capacity.

A key advantage of the predictive control system is its ability to better utilize the buffer storage, make use of flexible electricity prices, and reduce modulation of the biomass boiler. Historically, the biomass boiler met heat demand very precisely, but lacked the flexibility enabled by integrating the heat pump and post-heating. The optimisation now allows for cost reductions by prioritizing the heat pump and post-heating during low electricity prices, while the biomass boiler takes over during more expensive phases or when waste heat is unavailable.

In summary, this demonstration case shows how waste heat can be utilized via a heat pump to replace the biomass boiler / oil boiler during summer and to assist the biomass boiler during transition periods. This hybrid heat generation system can be operated most cost-efficient by a data-driven, predictive control strategy.

3.3 District heating network Saalfelden

3.3.1 Description and realised concept

The demonstration site Saalfelden represents a larger biomass-based DH system that has been in operation since 1997. The district heating network, established in 2018, comprises approximately 5.3 km of pipeline and around 50 substations. Within BM Retrofit, Saalfelden served as a key demonstration case for the integration of advanced efficiency-enhancing technologies at plant level and for network expansion combined with fossil fuel substitution. The overall objectives at this site were to increase the overall plant efficiency, reduce fossil fuel use (natural gas), improve combustion quality, integrate active flue gas condensation with heat pumps, and strengthen the network infrastructure to enable higher heat delivery to the network.

Figure 12: DH plant in Saalfelden. Source: Klimafonds / Krobath

The modernisation measures were implemented in two phases. In Phase I (2020), a flue gas condensation system was integrated into the biomass boiler plant to recover low-temperature heat from the exhaust gases. In Phase II (2023–2025), a cascading heat pump system with 3 × 250 kW_{th} (Figure 13) was installed to actively increase the recovered flue gas condensation heat. In parallel, the main supply line of the network was reinforced to increase transport capacity.

Figure 13: Cascading heat pump system (3 × 250 kW). Source: Klimafonds / Krobath

To optimize the biomass boiler operation, detailed investigations were performed for an increase in boiler efficiency as well as the reduction of the O_2-content in the flue gas to guarantee complete gas-phase burn-out conditions combined with stable and more efficient boiler operation. Based on the results, a CO-lambda optimisation system (Figure 14) was implemented within Phase II (2023–2025) of the modernisation measures. It was tested for the specific boiler configuration and used to optimize the settings of the boiler control system.

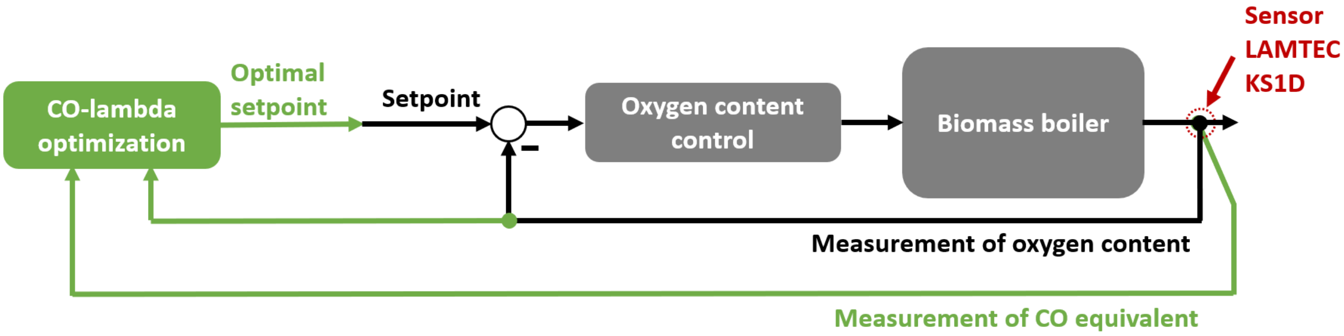


Figure 14: Integration scheme of the CO-lambda optimisation. Existing hardware in gray, additional hardware for the optimisation in green. Source: BEST

3.3.2 Data analysis and monitoring

Network Expansion and Reduction of Fossil Fuel Use

As a result of network reinforcement and expansion, the total annual heat delivery increased significantly from 13.1 GWh in 2019 to 17.4 GWh in 2025. Despite the increased demand, the share of natural gas in total heat generation was reduced from 11.3% to 3.3% (see Figure 15). This reduction was primarily achieved through the integration of flue gas condensation combined with the cascading heat pump system, which allowed higher heat output from the biomass boiler system and reduced the need for fossil peak-load support. The demonstrator thus shows that efficiency-enhancing retrofits can simultaneously enable network growth and fossil fuel substitution.

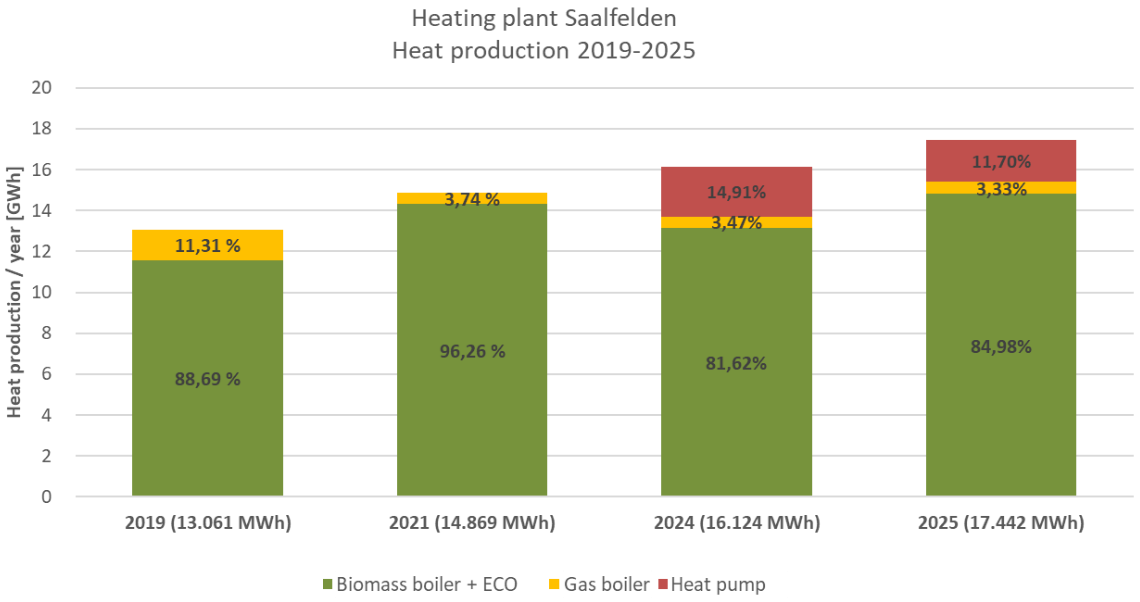


Figure 15: Development of yearly heat production and share of energy sources

CO-lambda optimisation

Data analysis of boiler operation at Saalfelden revealed key factors influencing CO emissions and combustion quality. High O_2 levels in flue gas often prevented CO formation due to oxygen scarcity, but incomplete combustion—caused by excessive gas velocities or insufficient residence time in the hot zone—remained a critical issue, particularly at high boiler outputs. Combustion chamber temperatures rarely exceeded 800°C, the threshold for optimal burnout. Moist fuel (containing snow, ice, or water from outdoor storage) worsened combustion, but increased heat recovery via flue gas condensation, requiring a trade-off.

The CO-lambda optimisation dynamically adjusts air supply based on CO-equivalents and O_2 values to improve combustion. However, its effectiveness was limited by the O_2 controller's poor performance, especially during low-load or unstable phases, where setpoints were frequently missed. A major challenge was the required manual adjustment of the biomass boiler, including flow limits (primary/secondary/tertiary air, recirculated flue gas) and temperature thresholds. While automated adaptation (e.g., tied to thermal output) was proposed to enhance efficiency and reduce emissions, collaboration with manufacturers yielded no final solution yet.

Manual optimisation using a CO-equivalent sensor significantly improved combustion: Between comparable periods (nominal load), CO emissions dropped fivefold (from 2,526 to 526 CO-equivalents, comparing February vs. December 2025 averages), and ash quantity halved.

3.3.3 System evaluation and optimisation potential

Life Cycle Assessment

For the demo Saalfelden the evaluation is based on a comparison of the reference year 2019 before BM Retrofit and 2025 after implementation of measures within the project. The implementation includes the connection of additional buildings to the DH grid due to the BM Retrofit measures. The results show a decrease of the GWP by 70% and of the CED by 8%. The decrease of the GWP is due to the decreased operation of the gas boiler as well as due to the substitution of fossil heating systems in those buildings additionally connected to the DH grid. Since the contribution of the heat pump to the total heat demand is relatively small, the decrease of the CED is also relatively small, since all other heating systems show a similar total CED.

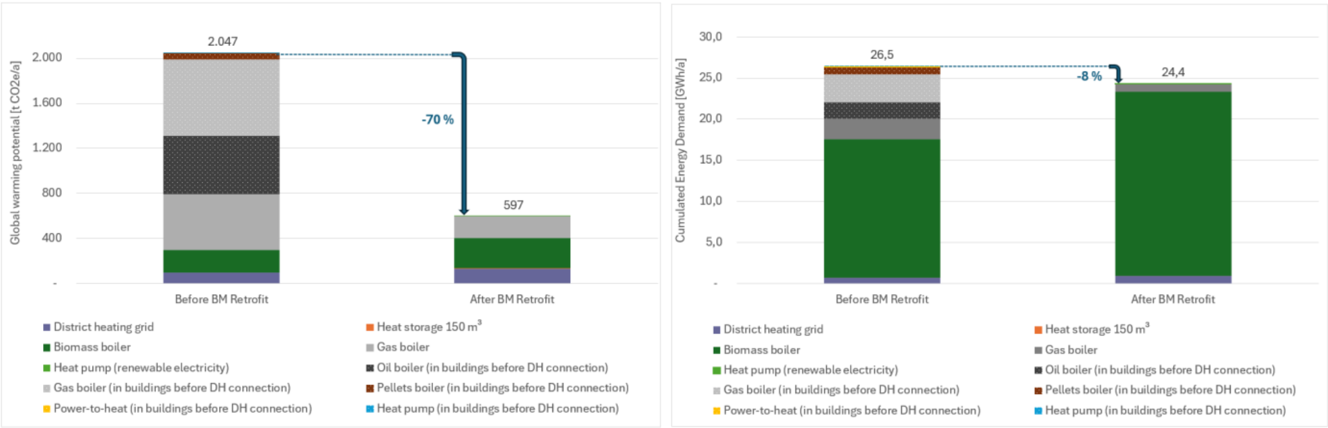


Figure 16: Yearly GWP and CED of the demo Saalfelden

Value Chain Analysis

For Saalfelden two investment phases – 2020 and 2023 – have been considered. In 2020 €1.955 million have been invested in the combustion system, flue gas technology, building control technology and heat recovery. In 2023 this was followed by an investment of €489,000 into heat pumps. This resulted in a reduction of 40kg CO_2 per €1.000 of investment over the considered lifetime.

The energy prices used in the analysis are based on information provided by the project partners for 2025. The following prices were used as a basis: €170.0 per MWh for electricity (including network costs), €46.5 per MWh for gas (including network costs), and €25.0 per MWh for biomass.

For the additionally integrated households in the district heating, hypothetical costs for the reference system have been estimated. These include energy costs, maintenance costs and reinvestment costs an individual heating system. For the gain in floor space through the replacement of the heating system with a transfer station the half of the average rental price per m2 was considered.

The results show that the measures implemented in Saalfelden since 2019 have led to an increase in annual value added in Austria of approximately €600,000 per year within the lifetime of the investment.

At the same time, there is a decrease in value added abroad of approximately €62,000 annually. This has resulted in a slightly positive employment effect in Austria.

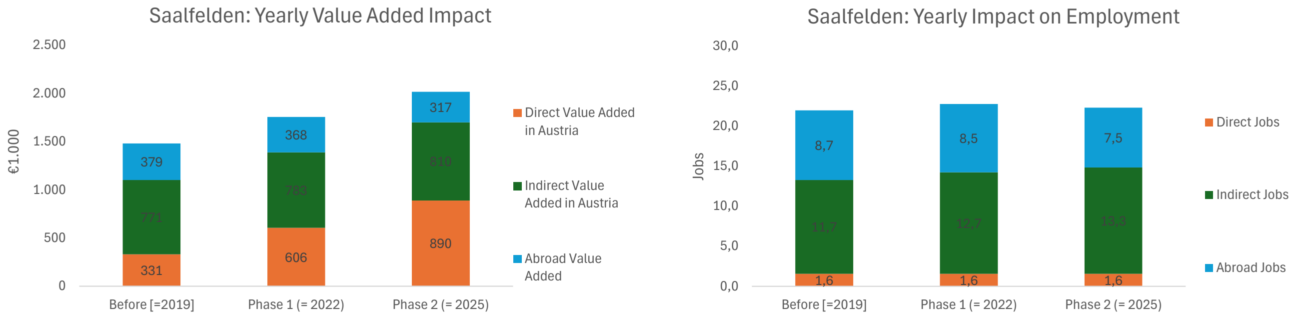


Figure 17: Yearly economic impacts of the demo Saalfelden

However, the results clearly depend on the assumed energy prices and their future development. Biomass is clearly cheaper than electricity. To replace it profitably, a high COP is required.

3.4 District heating network Kreuzstetten

3.4.1 Description and realised concept

The demonstration case Kreuzstetten represents a medium-scale biomass-based DH network with around 160 consumers via an 8,700-meter-long heating network, with an annual heat demand of approximately 5.5 GWh. The facility consists of two biomass boilers, each with a capacity of 1 MW_{th}, a 40 m³ buffer storage tank, and an 88.5 kW_p photovoltaic system. The biomass boilers are oversized for the heat demand as a significant increase in consumers was expected that did not take place. This challenges the operation of the biomass boilers as they are regularly forced into partial load with reduced efficiency and often shut-down and start-up again. Another challenge is a pumpkin seed dryer that demands a very high head load for a short time. Key issues included a low summer load, which led to increased heat losses, as well as inefficient operation of the biomass boilers. Additionally, the temperatures in the DH network were rather high and needed to be reduced.

Figure 18: Installed PV collector field in Kreuzstetten. Source: Equans

At the beginning of the project a comprehensive analysis of the DH system in Kreuzstetten was performed. The evaluation via the “BM Retrofit Anlagencheck” showed that an extremely low summer load with corresponding high heat losses of up to 65% are a major challenge. During this time, the biomass boilers (2 x 1 MW_{th}) are operated below 20% of their nominal load, which forces the boilers into stop-and-go operation.

3.4.2 Data analysis and monitoring

Reduction of System Temperatures and Network Optimisation

In parallel to generation-side measures, network optimisation was carried out. A detailed customer-side analysis identified open bypass flows and suboptimal heat exchanger settings as major causes of high return temperatures. Through targeted optimisation of substations and elimination of bypass flows, the average network return temperature was reduced from 55–60°C to 40–45°C, corresponding to a reduction of approximately 15°C. As a result, the temperature spread between supply and return increased by about 13°C and led to a reduction of the specific volume flow by 13 m^3/MWh heat delivered. Consequently, the electricity consumption of network pumps was reduced by approximately one third. These improvements directly enhanced overall system efficiency and reduced operational costs.

Besides the plant operation, the DH network was analysed regarding its current state in terms of temperature load, pressure load and bottlenecks. These were applied for thermo-hydraulic simulations. Exemplary results from Simplex simulations performed by PINK are shown in Figure 19. The simulations resulted, that there are no weaknesses or bottlenecks of the DH network at the moment.

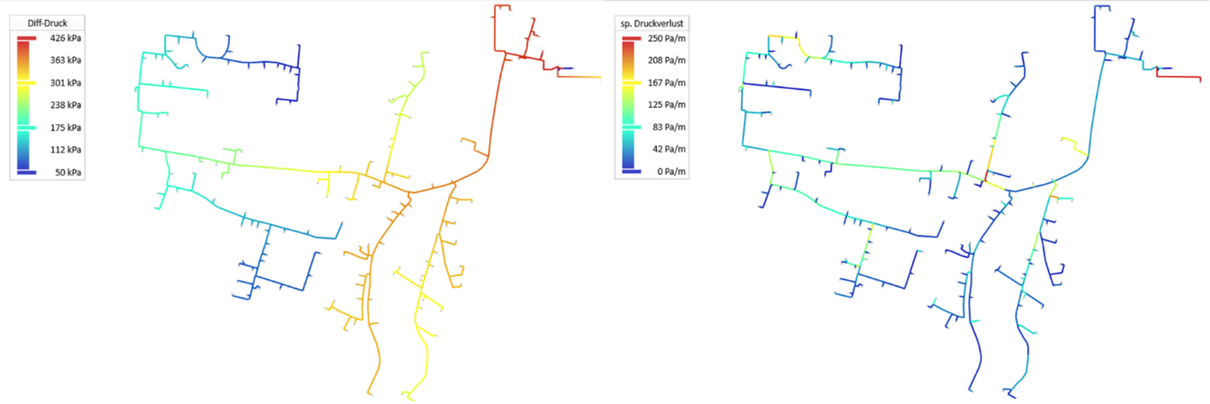


Figure 19: Results from thermo-hydraulic simulations of the DH network Kreuzstetten (Source: PINK)

Improved buffer management for improved boiler operation

A detailed analysis of the boiler operation for a period of 7 days that covers part load operation as well as full operation is presented in Figure 20. This analysis shows that the set feed temperatures are kept stable and the outputs are realised well. However, both boilers are in operation during the part load phase, although one boiler alone could cover the required output. During the full load phase, both boilers frequently switch between switched off, minimum load and nominal load instead of a constant operation at a certain load.

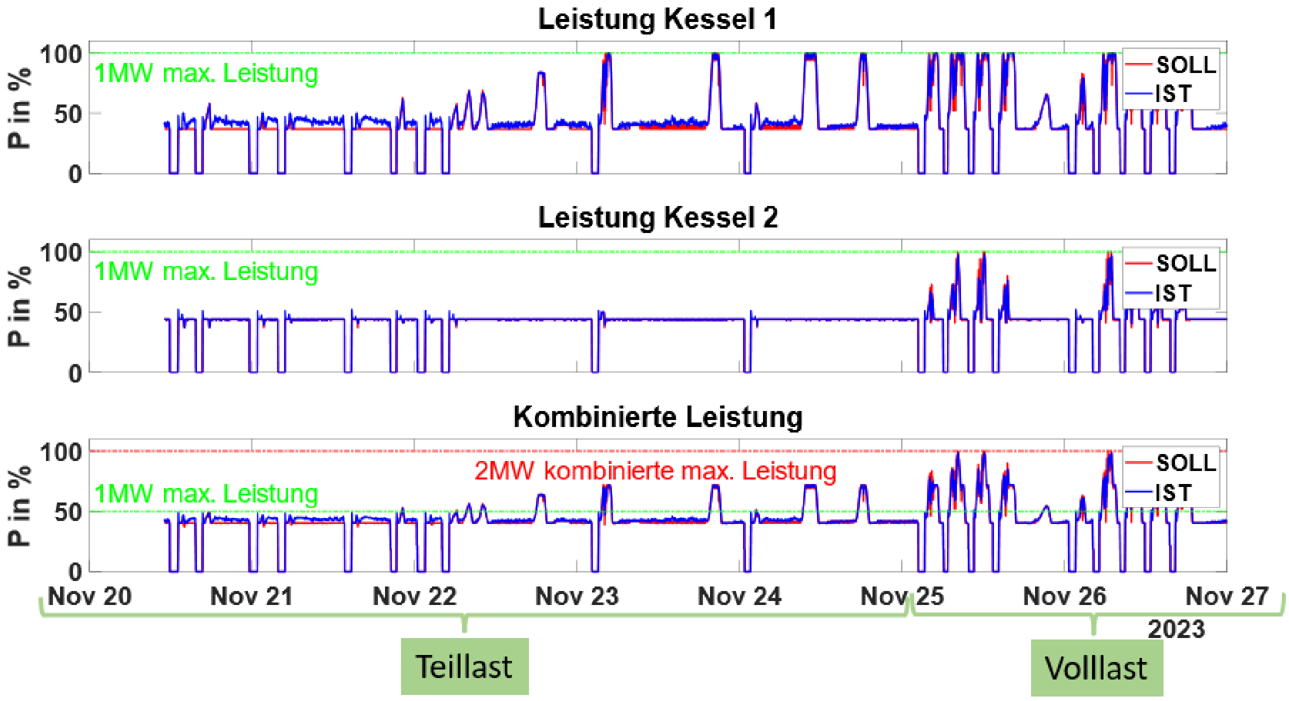


Figure 20: Boiler operation over a period of 7 days before improvement of the buffer management (Source: BEST)

An iterative improvement of the buffer management lead to significant reductions in start-up/shut-down cycles. Given the comparatively large biomass-boilers the improvement can be seen most prominently in the use of the buffer volume by analysing the temperature profiles within buffer storage. Here, the temperature profiles before improvement showed little use of the buffer storage to eliminate strong modulation and start-up/shut-down cycles of the biomass boiler. After improved puffer management the temperature profiles show complete use of the buffer volume installed. Thus, the potential for improvement by rule-based puffer management was lifted.

3.4.3 System evaluation and optimisation potential

Heat Pump integration

To address inefficient summer operation of the oversized biomass boilers, a dedicated summer solution based on an air-source heat pump was investigated using energy system simulations (energyPRO). Different heat pump capacities between 300 and 400 kW$_{th}$ were analysed, based on the summer load in 2024. Simulation results indicate that a 300 kW$_{th}$ heat pump could cover summer demand from early May to mid-September, corresponding to approximately 13% of annual heat demand. The distribution of heat production for the biomass and heat pump system (300 kW$_{th}$) is presented in Figure 21. For this configuration, total annual electricity demand would increase from 110 to 360 MWh, of which ~21% could be supplied by the on-site PV system and the rest would be imported from the grid. Further economic assessment is required to determine the optimal heat pump capacity considering investment costs and electricity price developments.

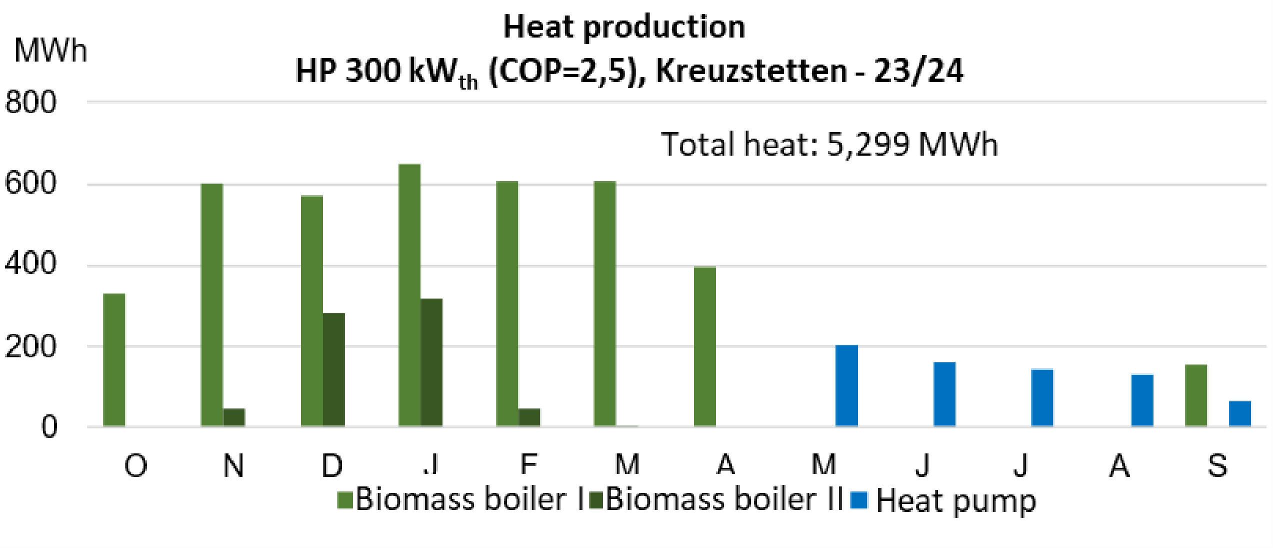


Figure 21:Monthly heat production mix for the heat pump scenario

Predictive Control Strategy

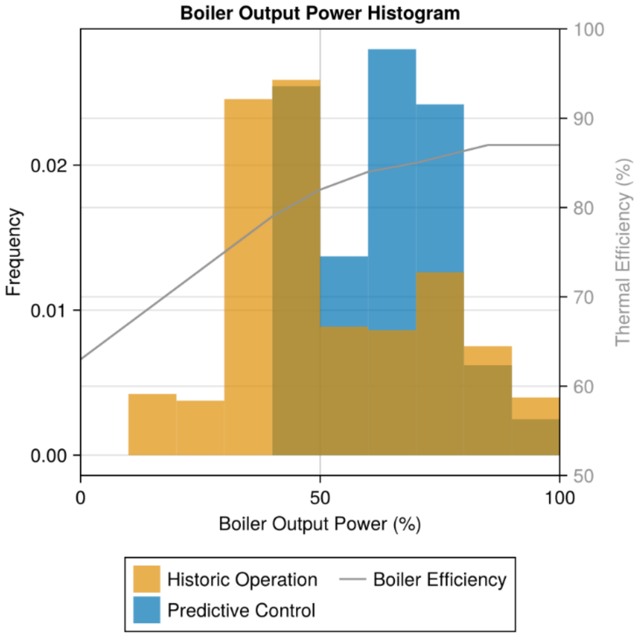


Figure 22: Accumulated boiler operation during heating period from 01-05/2024 comparing historic (rule-based) operation with predictive control. Source: BEST.

A further improvement of the buffer management could be established by a predictive control system. To quantify this improvement simulation studies comparing predictive control with the rule-based controller were performed. Here the heating period and the pumpkin seed drying period were addressed individually. During heating period (01–05/2024) the predictive control reduced the start-up/shut-down cycles by 22% and operated the biomass boilers less often in low partial load as visual in the histogram in Figure 23.

During the pumpkin seed drying period the results showed that the rule-based controller was not suitable for all operating conditions, leading to inefficient preheating of the buffer storage. By implementing predictive control, the number of start-up/shut-down cycles was cut by 50%. Here, a key approach was the pre-loading of the buffer storage during times of potential pumpkin seed drying by setting a minimum storage level.

The results of the simulation study demonstrate further advantages of predictive control: it allows operational requirements to be directly defined, such as setting a minimum storage level or penalizing start-up/shut-down cycles. This not only leads to cost savings but also extends the lifespan of the systems. Overall, predictive control enables more efficient boiler operation, as the systems operate more frequently in optimal load ranges.

Life Cycle Assessment

For the demo Kreuzstetten the evaluation is based on a comparison of the reference year 2025 before BM Retrofit and 2026 after implementation of measures within the project. The implementation includes a heat pump scenario and the connection of additional buildings to the DH grid due to the BM Retrofit measures. The results show a decrease of the GWP by 17% and of the CED by 14%. The decrease of the GWP is due to the optimized operation of the biomass boiler as well as due to the substitution of fossil heating systems in those buildings additionally connected to the DH grid. The decrease of the CED is due to the optimized operation of the biomass boiler and the integration of the heat pump.

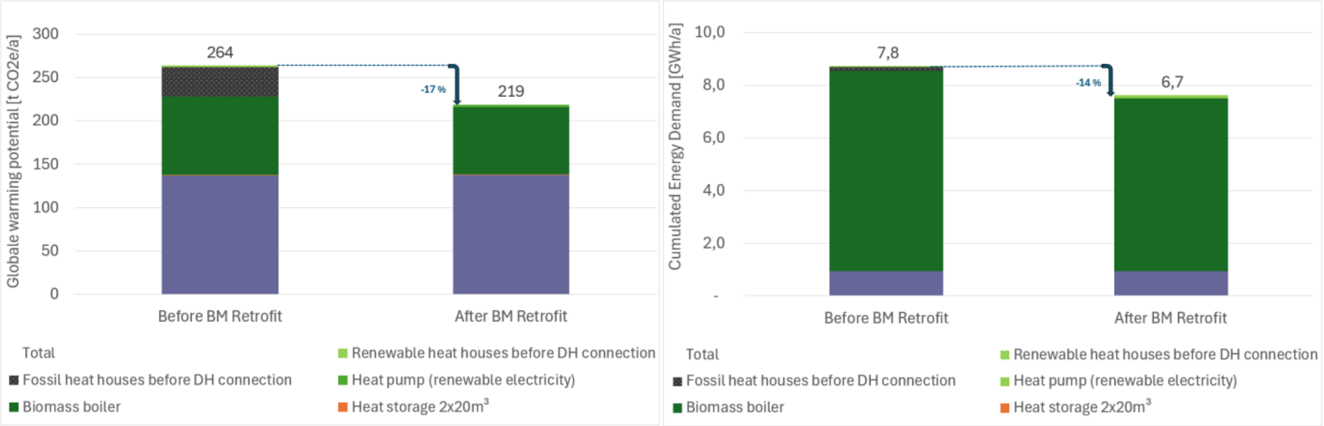


Figure 23: Yearly GWP and CED of the demo Kreuzstetten

Value Chain Analysis

For Kreuzstetten, the evaluation is based on a simulation of the integration of additional households and heat pumps. Compared to the reference case, two scenarios – heating system optimisations and additional households connected to the grid as well as additionally the integration of a heat pump – were analysed for the year 2025 and 2026. For the heat pump an investment of €400.000 was assumed. For electricity a price of €170 was assumed, for biomass 25€ per MWh.

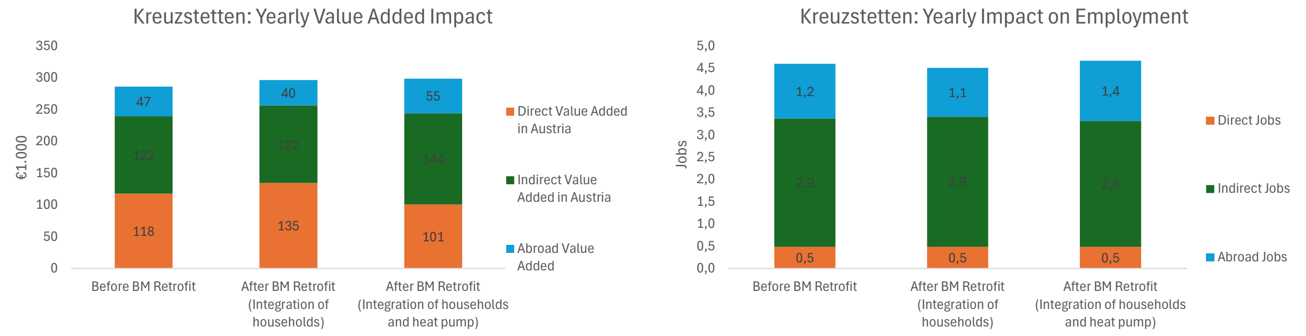


Figure 24: Yearly economic impacts of the demo Kreuzstetten

The planned measures in Kreuzstetten would lead to a slight increase in domestic value creation. Connecting new customers would increase annual domestic value creation by approximately €17,000. Integrating a heat pump would increase this by only €4,000. Direct value creation would increase significantly with the addition of new customers, whereas it would decrease if a heat pump were integrated. Overall, there would be a marginally positive employment effect, primarily for foreign workers.

The relationship between CO2 reduction and investment shows that for every €1,000 invested, approximately 93 kg of CO2 would be saved annually over the system's lifespan.

3.5 Solution approaches

In addition to the site-specific demonstration activities, BM Retrofit resulted in the development of a set of generic, transferable solution approaches addressing key technical and systemic challenges of existing biomass-based district heating networks. The individual solutions and retrofitting concepts for biomass-based DH networks were analysed in different use cases. These solution approaches were designed to be modular and scalable, enabling their application beyond the individual demonstration sites under varying boundary conditions.

- A core solution approach focuses on the integration of heat pumps into existing biomass-based systems, particularly for the utilisation of low-temperature heat sources such as waste heat from industrial processes, flue gas condensation or renewable electricity-driven power-to-heat applications. By coupling biomass boilers with heat pumps (thermal and electrical driven), overall system efficiency can be significantly increased, seasonal performance improved and operational flexibility enhanced. This hybrid configuration also enables a partial decoupling of heat generation from biomass availability and fuel price fluctuations.
- Another key solution approach addresses advanced control and optimisation strategies for biomass boiler operation and system integration. The implementation of sensor-based control concepts, such as CO lambda probes, enables a more precise combustion control, leading to higher efficiency, reduced emissions and improved operational stability. In combination with predictive and demand-oriented control strategies, these approaches allow for a more flexible and responsive system operation, particularly under fluctuating load conditions.
- The project further developed solution approaches related to thermal storage integration and management. Adequately dimensioned buffer storage systems were identified as essential components for increasing system flexibility, decoupling heat generation from demand, and reducing unnecessary cycling of biomass boilers and auxiliary units. Optimised storage management strategies contribute to smoother load profiles, improved component lifetimes and enhanced overall system reliability.
- A further solution approach focuses on network-level optimisation, including thermohydraulic simulation-based planning tools for network expansion, densification and retrofit measures. These tools enable a data-driven assessment of network performance, identification of bottlenecks and evaluation of measures to reduce return temperatures and distribution losses. Secondary-side measures at the consumer level were shown to be particularly effective in lowering return temperatures, thereby increasing the efficiency of both biomass boilers and integrated heat pumps.
- In addition to technical solutions, BM Retrofit also developed organisational and business model–oriented solution approaches. These include adapted operational strategies, revised tariff structures and business models that better reflect the increased system flexibility and the integration of multiple heat generation technologies. Such approaches are crucial to ensure the

economic viability of retrofit measures and to support long-term investment decisions by network operators.

Overall, the developed solution approaches form a coherent, system-oriented toolkit for the modernisation of biomass-based district heating networks. Their successful implementation and validation under real operating conditions demonstrate their robustness, transferability and high potential for replication in comparable systems at national and European level.

4 Actor integration and innovation process

Chapter 4 focuses on the innovative and comprehensive integration of relevant actors and stakeholders. Through the systematic involvement of key actor groups, the project aims to strengthen the social feasibility, regional embedding, and long-term implementation of the technological solutions developed within the project.

4.1 Actor identification

Within the project, a comprehensive and systematic approach was applied to identify and analyse the relevant actors involved in and affected by the demonstration sites. This process formed the foundation for all subsequent stakeholder engagement and innovation activities.

The identification phase was carried out through a combination of on-site visits, workshops and structured exchanges with demonstrator operators and regional stakeholders. At each demonstration site, the technical infrastructure, organisational setting and regional context of the heating plants were analysed in detail. Particular attention was given to understanding the historical development, operational characteristics and future challenges of the systems, as well as the relationships between involved actors. Based on these activities, a broad range of stakeholders was identified, including district heating operators, technology providers, planners, public authorities, funding bodies, customers, local communities and other relevant actors within the regional energy system. Their roles, interests, influence and interdependencies were systematically assessed.

A key result of this process was the development of structured stakeholder matrices for each demonstrator (see Figure 25). These matrices provided a transparent overview of the relevant actors across the value chain and enabled a differentiated assessment of their relevance for planning, implementation and operation. In addition, an inventory and status analysis of each demonstrator was conducted, linking technical system characteristics with organisational and stakeholder-related aspects. Together, these outputs established a robust analytical basis for targeted actor integration and ensured that the subsequent innovation processes were grounded in a detailed understanding of the local context.

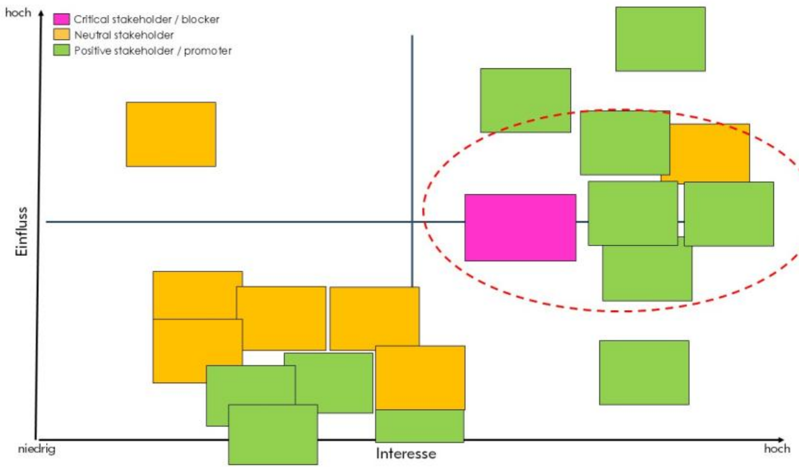


Figure 25: Exemplary stakeholder matrix, Source: StadtLabor

4.2 Actor integration and innovation Process

Based on the stakeholder identification and analysis, the project implemented a structured and multi-level approach to actor integration, aiming to actively involve relevant stakeholders in the development and implementation of retrofit concepts.

A central element of this approach was the establishment of continuous exchange and collaboration formats, bringing together project partners, demonstrator operators and selected stakeholders. These structures enabled ongoing dialogue, facilitated knowledge transfer and supported the co-creation of technical and organisational solutions. Rather than limiting stakeholder involvement to consultation, the project created spaces for joint reflection and problem-solving, thereby increasing commitment and ownership among the involved actors.

At the demonstrator level, targeted communication and engagement measures were implemented to ensure transparency and foster acceptance. These included stakeholder workshops, public relations activities and open-door events, which allowed direct interaction between project partners, operators, policymakers, researchers and citizens. Such formats contributed to strengthening local awareness of the retrofit measures and supported the positioning of district heating systems as integral components of regional energy transitions.

In the final project phase, actor integration was further expanded through the introduction of open and participatory innovation formats. A key activity in this context was the organisation of a digital innovation challenge via the participation platform Stadt.Land.Ideen. Designed as a public competition, this format aimed to broaden the innovation process beyond the project consortium and actively involve universities, students, citizens and other interested stakeholders. Under the title “Hot for a climate-friendly future: the ideas competition for biomass heating plants”, participants were invited to develop ideas addressing the future role of heating plants as multifunctional regional energy actors. The thematic scope included the integration of heating systems into circular economy structures, the utilisation of regional resources and waste heat, the provision of additional services and the development of new business models beyond conventional heat supply.

Heiß auf eine klimafitte Zukunft: Der Ideenwettbewerb für Biomasseheizwerke

Gemeinsam die Zukunft der Biomasseheizwerke gestalten!

Bringe deine Ideen ein und hilf mit, Biomasseheizwerke fit für die Zukunft zu machen!

Figure 26: Digital Innovation Challenge

The competition was widely disseminated through partner networks, newsletters, sectoral organisations and targeted communication with academic institutions. Over a period of seven weeks, a range of innovative ideas was collected. The submitted contributions were evaluated by a jury composed of project partners, and the best ideas were presented within the project consortium. This enabled a direct exchange between external contributors and project stakeholders and generated valuable additional perspectives for the further development of the project results.

In parallel, structured stakeholder engagement processes were further developed in the context of the district heating plant in Hochwolkersdorf. In this case, support was provided for the communication and integration of stakeholders during the takeover and modernisation of the plant. Based on a dedicated stakeholder analysis, a targeted engagement process was designed, including customer communication, press activities and the organisation of a public open-door event. Several coordinated measures were implemented, including the preparation and distribution of customer information, the publication of press releases and the organisation of the open-door event. The event attracted strong interest from local residents, neighbouring municipalities and sector representatives and was accompanied by media coverage. These activities contributed to increased transparency, strengthened trust among stakeholders and supported the smooth implementation of the retrofit measures.

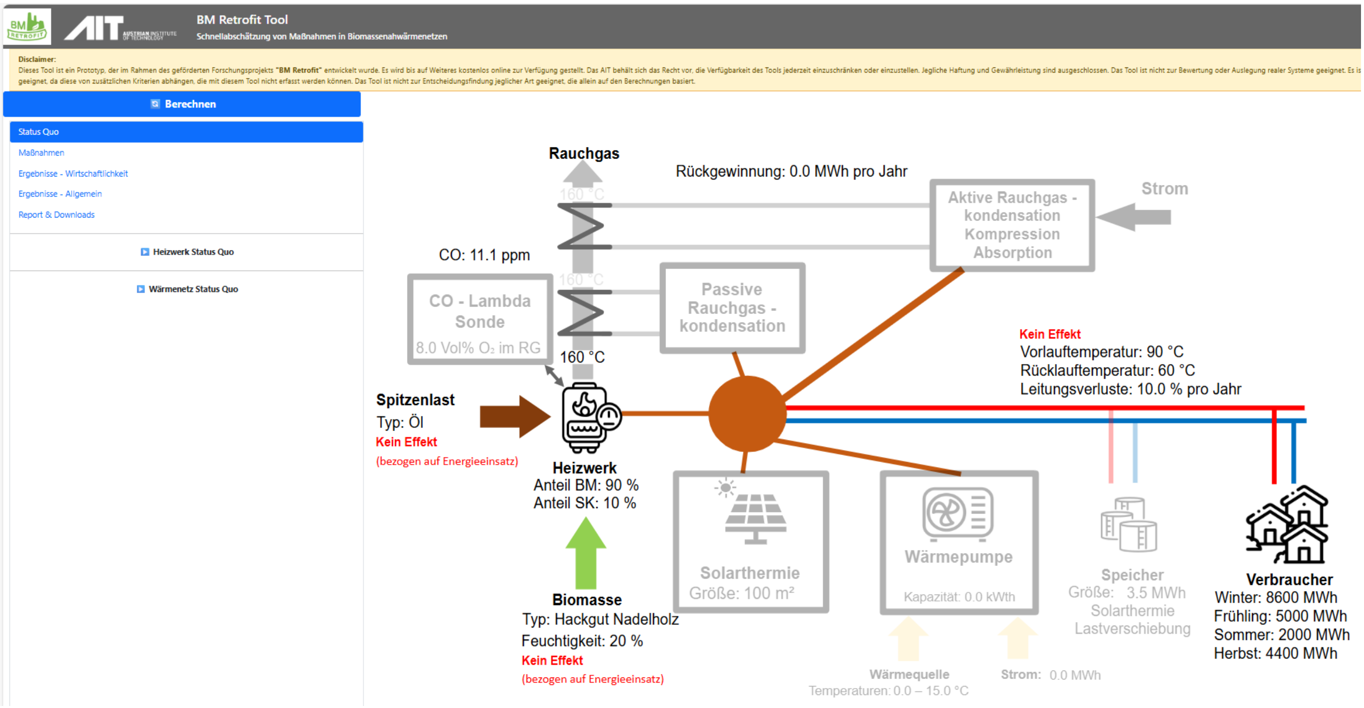
Overall, the project established a comprehensive actor integration approach combining analytical tools, continuous engagement formats and open innovation processes. This approach enabled a transition from stakeholder identification and consultation towards active co-creation. As a result, regional embedding was strengthened, social acceptance was increased and the developed solutions were enriched by practical and user-oriented perspectives. The experience gained demonstrates that early, continuous and well-structured actor integration is a key success factor for the implementation and transferability of complex energy system innovations.

5 Business model and market potential

The retrofitting concepts developed within BM Retrofit are designed as transferable solutions for the broader Austrian biomass district heating sector. This chapter addresses their economic viability and scaling potential beyond the demonstration sites. A web-based Decision Support Tool provides structured techno-economic assessments at plant level and forms the methodological basis for a national roll-out analysis using clustered district heating systems and feeds into a sector-wide impact assessment.

5.1 Business model tool

Within BM Retrofit, a web-based Decision Support Tool was developed to support biomass district heating operators in evaluating modernisation and retrofit measures. The tool specifically addresses small and medium-sized district heating operators, municipal utilities, energy agencies and engineering consultants requiring a structured early-stage assessment of retrofit options. It is available as an open-access web application at https://bm-retrofit-tool.ait.ac.at/tool and is designed as a pre-feasibility screening instrument, not a replacement for detailed engineering design. Its primary purpose is to enable transparent comparison of retrofit pathways, identify economically viable measures, and support preparation of investment decisions and funding applications.



BM Retrofit Tool
Schnellabschätzung von Maßnahmen in Biomassenahwärmenetzen

Disclaimer:
Dieses Tool ist ein Prototyp, der im Rahmen des geförderten Forschungsprojekts **"BM Retrofit"** entwickelt wurde. Es wird bis auf Weiteres kostenlos online zur Verfügung gestellt. Das AIT behält sich das Recht vor, die Verfügbarkeit des Tools jederzeit einzuschränken oder einzustellen. Jegliche Haftung und Gewährleistung sind ausgeschlossen. Das Tool ist nicht zur Bewertung oder Auslegung realer Systeme geeignet. Es is geeignet, da diese von zusätzlichen Kriterien abhängen, die mit diesem Tool nicht erfasst werden können. Das Tool ist nicht zur Entscheidungsfindung jeglicher Art geeignet, die allein auf den Berechnungen basiert.

Rückgewinnung: 0.0 MWh pro Jahr
CO: 11.1 ppm
Kein Effekt
Vorlauftemperatur: 90 °C
Rücklauftemperatur: 60 °C
Leitungsverluste: 10.0 % pro Jahr

Spitzenlast
Typ: Öl
Kein Effekt
(bezogen auf Energieeinsatz)

Heizwerk
Anteil BM: 90 %
Anteil SK: 10 %

Biomasse
Typ: Hackgut Nadelholz
Feuchtigkeit: 20 %
Kein Effekt
(bezogen auf Energieeinsatz)

Verbraucher
Winter: 8600 MWh
Frühling: 5000 MWh
Sommer: 2000 MWh
Herbst: 4400 MWh

Figure 27: Screenshot BM Retrofit Tool (Source: https://bm-retrofit-tool.ait.ac.at/tool).

5.1.1 System model and seasonal resolution

The tool models a biomass-based district heating system consisting of a biomass boiler, a peak load unit (gas, oil or electric) and an aggregated consumer structure. The load split between biomass boiler and peak load unit is based on a generic Austrian load profile with the biomass share defined by the user. Storage and heat pump integration directly displace peak load, consistent with the roll-out logic in 5.2.

Seasonal effects are represented by four quarterly time steps covering winter base load, spring, summer low load and autumn conditions. Network heat losses are calculated as a function of supply temperature, return temperature and ground temperature, making results sensitive to return temperature reduction and solar integration.

5.1.2 Implemented retrofit measures

The tool implements the following measures, each based on physically consistent calculation models:

- CO/Lambda probe: Boiler efficiency is derived from the relationship between oxygen content, fuel moisture and flue gas losses using combustion stoichiometry. No fixed efficiency assumption is used.
- Passive flue gas condensation: Sensible and latent heat recovery is calculated as a function of flue gas cooling, return temperature and fuel moisture, including dew point determination.
- Active flue gas condensation with compression heat pump: Heat is recovered below return temperature level. COP is calculated via the Carnot principle as a function of temperature lift. Electricity demand is derived explicitly.
- Active flue gas condensation with absorption heat pump: Thermally driven heat recovery below return temperature level using empirical performance parameters. No electricity input required.
- Compression heat pump with external waste heat source: Models return temperature elevation and source-dependent COP. Biomass and peak load displacement are calculated explicitly alongside electricity consumption.
- Solar thermal integration: Solar yield is calculated using ZAMG radiation data for all nine Austrian state capitals and collector efficiency curves as a function of temperature. Yield decreases at high network temperatures.
- Thermal storage: Modelled for two functions: solar yield boosting and peak load shifting. The model assumes ideal mixing and no storage losses.
- Combination of measures: Interactions between measures are considered within the calculation framework.

5.1.3 Inputs, outputs and economic evaluation

Key inputs are annual heat demand, boiler capacity, supply and return temperatures, peak load share, biomass price, electricity price and a user-defined discount rate (default 5%). For each measure the tool calculates biomass savings, electricity demand, solar yield, peak load reduction, CO_2 emission reduction, CAPEX, OPEX, annual system costs, static payback period and net present value. Economic evaluation uses the annuity method with technology-specific default lifetimes ranging from 10 years (CO/Lambda probe) to 30 years (thermal storage). Price sensitivity to biomass and electricity prices can be assessed directly, which is particularly relevant for heat pump economics.

Outputs are provided in a transparent and standardised format, allowing users to export results as PDF reports for documentation and stakeholder communication. The interface allows rapid parameter variation, enabling sensitivity analyses for electricity and biomass price scenarios.

The tool includes a pre-feasibility scope by design. Key simplifications are quarterly average values instead of hourly simulation, idealised storage operation without losses, no hydraulic network modelling and no detailed NOx/CO emission modelling. These simplifications are intentional and ensure robustness, fast computation times and broad applicability without requiring extensive input data.

5.1.4 Validation and integration

Calculation models were validated against monitored operational data from the BM Retrofit demonstration sites and cross-checked with detailed simulation results. The tool is methodologically consistent with the cluster-based simulation framework in 5.2, applying the same techno-economic logic at both plant level and national roll-out level. It represents a central exploitation output of the project and supports the transfer of retrofit concepts beyond the demonstration sites.

5.2 Scaling scenarios, impact assessment and roadmap

The objective of this part of the project was to develop scenarios for the roll-out of retrofitting measures in Austrian biomass district heating grids and to assess electricity load-shifting potentials as flexibility option to the wider energy system.

5.2.1 Methodology

In order to assess scaling scenarios and market potentials for retrofitting biomass district heating grids in Austria, we first grouped Austrian biomass district heating grids into representative clusters based on technical and spatial characteristics. For each cluster, simulation scenarios were generated by combining retrofit measures with the defined price assumptions. Each technically feasible retrofit measure, including individual measures and their combinations, was simulated under each biomass and electricity price combination, yielding a comprehensive matrix of techno-economic outcomes. For this purpose, the simulation described in chapter 5.1 was used. The simulation outputs from this tool include annual biomass savings, peak load displacement, electricity consumption for heat pump operation, capital expenditure (CAPEX), operational expenditure (OPEX), and net present value (NPV) calculated over a 20-year project lifetime with a 5% discount rate.

The data on individual district heating plants were obtained from the QM Heizwerke database which is maintained as part of the Austrian Klimaaktiv programme for efficient heating plants and district heating networks. The database records technical and operational parameters for plants that receive public investment subsidies, covering installations with a nominal boiler capacity exceeding 400~kW or a network length above 1,000~m. The clustering used both technical and spatial features. Technical parameters included boiler capacity, thermal efficiency, fuel moisture content, and supply and return temperatures. Spatial features included the waste heat potential in the plant's vicinity, grouped by temperature level (below 50°C, 50-100°C, and above 100°C), as well as low-temperature heat from nearby hydropower plants

Following the clustering of district heating plants, a systematic techno-economic evaluation was conducted to assess the viability of retrofit measures for each cluster. This evaluation comprised scenario generation, energy and cost simulation, economic comparison, and the formulation of sector-wide rollout pathways under different market conditions.

Five categories of retrofit measures were considered, representing distinct technological approaches to improving plant efficiency and reducing primary energy consumption:

- Lambda control optimisation (COL)
- Passive flue gas condensation (PFG)
- Active flue gas condensation (AFG)
- Compression heat pump integration (HP)
- Combination of measures

The technical feasibility of each measure was determined by cluster characteristics. For each cluster under a given price scenario, the retrofit measure with the highest positive net present value was selected.

To explore the range of possible sector-wide outcomes, three rollout scenarios were defined based on the electricity price assumptions:

- Max HP scenario: Assumes a low electricity price. Under these conditions, compression heat pumps achieve favorable economics where waste heat sources are available, resulting in higher deployment of electricity-based heat integration.
- Max AFG scenario: Assumes a high electricity price. Heat pump economics deteriorate under high electricity costs, shifting the optimal measure selection toward active flue gas condensation and other measures not requiring electricity input.
- Min scenario: The scenario represents a conservative baseline with slow market adoption (5\% by 2030, 45\% by 2050) and assumes suboptimal implementation achieving 75\% of theoretical savings.

Each scenario was evaluated for two biomass price levels, yielding six distinct rollout configurations. The scenario naming reflects the technology that tends to dominate under each price assumption, though actual measure selection varies by cluster based on individual techno-economic characteristics.

To quantify the flexibility potential of waste-heat heat pumps (HPs) under time-varying electricity prices, we compare two dispatch model runs for each representative cluster: (i) a constant electricity price case (baseline), and (ii) an electricity price profile case. Both runs use identical technical constraints and heat demand, so differences in electricity consumption stem solely from price-driven operational shifts.

5.2.2 Scenarios

Figure 28 shows the results for the roll-out scenarios indicating the potential uptake of different measures by 2030, 2040 and 2050 in three different scenarios each under two different biomass price scenarios (labelled as BM 72 and BM 48.5 in Figure 28).

Active flue gas condensation dominates across all scenarios, accounting for 36–84\% of adopting plants. Adoption of heat pumps sourced by waste heat, by contrast, faces two key barriers: half of all clusters lack accessible waste heat sources, and economics deteriorate sharply when biomass prices fall. At 72 EUR/MWh, heat pumps remain competitive where waste heat exists, but at 48.5 EUR/MWh the case weakens because heat pumps substitute biomass with electricity rather than simply reducing consumption.

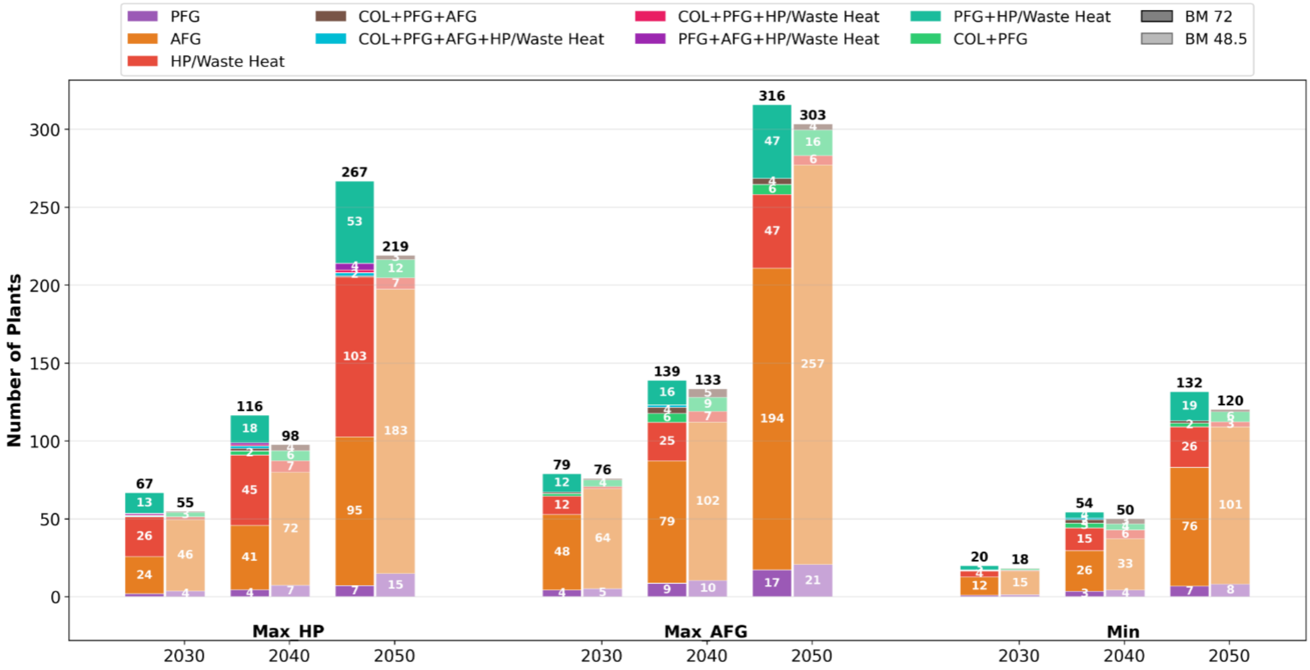


Figure 28: Roll-out scenarios showing the uptake of different retrofitting measures in Austrian biomass district heating grids.

Under the current modeling assumptions, single-plant clusters only adopt measures in 2040, while multi-plant clusters adopt incrementally over time. This timing directly impacts the investment needs and biomass savings shown in Figure 29.

In 2040, the higher space availability in the Max AFG scenario (70\% vs. 50\%) allows for a larger number of adoptions. It is important to note that plants facing space constraints do not switch to heat pumps; they simply do not adopt any measures. Similarly, in the Max HP scenario, if space constraints prevent AFG installation and heat pumps are not feasible, no adoption occurs. This results in more total adoptions in the Max AFG scenario, pushing its total investment higher than Max HP despite AFG's lower unit costs.

In 2030 and 2050, the data reflect only multi-plant clusters. In these years, the higher unit costs and greater savings from heat pump measures increase the totals in the Max HP scenario, even though fewer plants adopt. However, at low biomass prices, the contribution from heat pumps becomes minimal in both scenarios. In this case, the space availability advantage of Max AFG dominates all years, leading to both higher total investment and greater biomass savings.

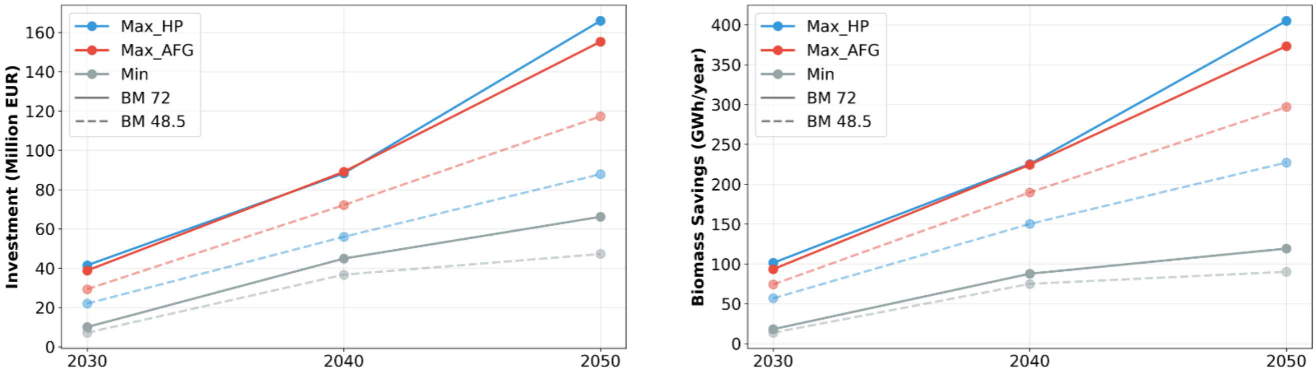


Figure 29: Cumulative investments and biomass savings in different roll-out scenarios of retrofitting Austrian biomass district heating grids.

District heating plants located near hydropower facilities can benefit from direct electricity supply at reduced rates, bypassing grid transmission costs. Figure 30 compares the levelized cost of heat pump configurations for the same 11 clusters under hydro electricity pricing (41 EUR/MWh) versus grid electricity (75-150 EUR/MWh). The median levelized cost drops from 70 EUR/MWh to 60 EUR/MWh when cheap hydro electricity is available. At grid electricity prices, most configurations exceed the high biomass price threshold, limiting their economic viability. With hydro access, the majority fall below this threshold, and several remain competitive even against the low biomass price of 48.5 EUR/MWh. This suggests that strategic co-location of heat pumps with hydropower sources can substantially improve the economics of electrification in the district heating sector. This configuration is already being demonstrated in practice at the BM Retrofit DEMO project in Wald im Pinzgau, where a 250~kW heat pump utilizes waste heat from a nearby hydropower plant's cooling circuit, powered by locally generated electricity.

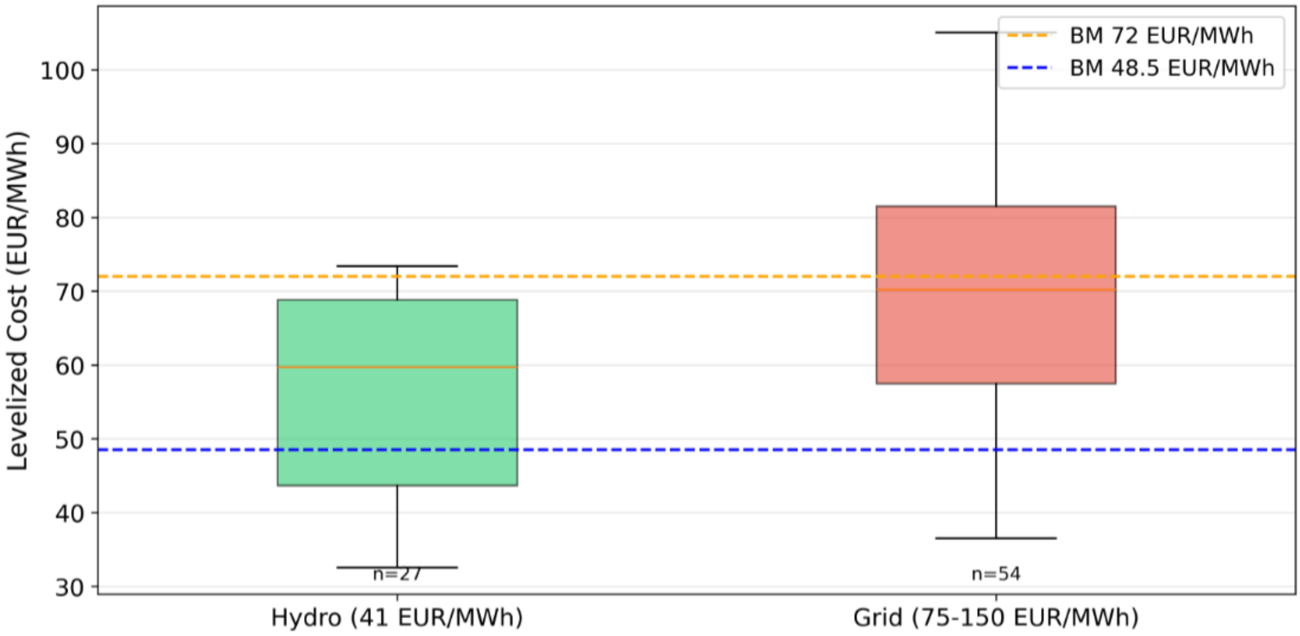
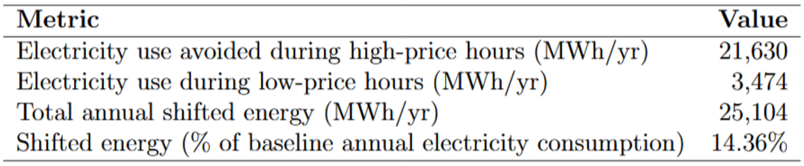


Figure 30: Effect of Hydro Power Plant Access on Heat Pump Levelized Costs.

In addition to evaluating the cost and biomass-saving performance of heat pumps using waste heat as heat source, we assess their operational flexibility under time-varying electricity prices. The flexibility analysis compares two dispatch runs for the same technical configuration and heat demand: a baseline case assuming a constant electricity price and a case using an hourly electricity price profile. Differences in hourly HP electricity consumption between the two runs, therefore, reflect the extent to which HP operation can be temporally reallocated in response to price signals.

Table 1. System-level annual load shifting results (all clusters and plants)



Metric	**Value**
Electricity use avoided during high-price hours (MWh/yr)	21,630
Electricity use during low-price hours (MWh/yr)	3,474
Total annual shifted energy (MWh/yr)	25,104
Shifted energy (% of baseline annual electricity consumption)	14.36%

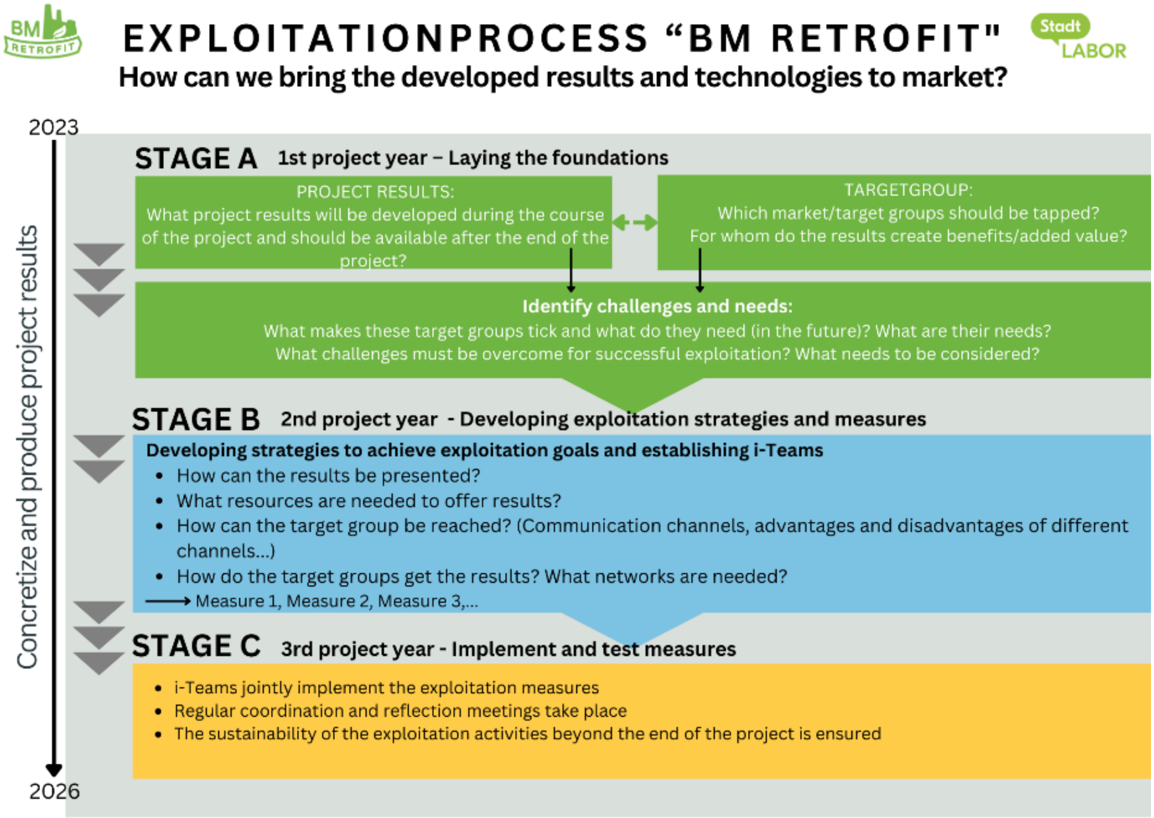
Table 1 summaries the system-level results aggregated across all clusters and weighted by the number of plants represented by each cluster. In total, 25 GWh of HP electricity use is shifted over the year, corresponding to about 14% of baseline HP electricity consumption in biomass district heating grids. The majority of this reallocation occurs as reductions during high-price periods (21.6 GWh), while the corresponding increases during low-price periods amount to 3.5 GWh. This asymmetry indicates that dispatch can curtail HP operation during expensive hours more strongly than it can increase operation during cheaper hours, reflecting binding operational constraints such as limited storage capacity and heat demand saturation during off-peak periods.

6 Exploitation and dissemination

Chapter 6 deals with the gained exploitation results and dissemination activities and focuses on the systematic exploitation and dissemination of the results generated within the BM Retrofit project. The activities addressed both the targeted utilisation of project outcomes by relevant stakeholder groups and the broad communication of results to scientific, professional and public audiences. Throughout the project exploitation and dissemination activities were continuously aligned with the technical progress of the demonstrators and the availability of validated results as well with the Green Energy Lab and Climate and Energy Fund.

6.1 Scientific and economic exploitation

Exploitation activities aimed at ensuring the long-term use, replication and impact of the results generated within the BM Retrofit project. Foundational exploitation activities were initiated early in the project through the development of a common exploitation plan template, complemented by partner interviews and initial exploitation workshops. These early activities established a shared understanding of exploitable results and provided a strategic framework for subsequent work. Through the project duration exploitation activities were significantly intensified and shifted towards implementation-oriented outputs and targeted stakeholder engagement. Scientific as well as economic exploitation was of high relevance for the scalability and transferability of the gained knowledge and outcomes of the project and was continuously carried out during the entire project. A professional exploitation process (see Figure 31) was established and implemented.



What project results will be developed during the course of the project and should be available after the end of the project?

Which market/target groups should be tapped? For whom do the results create benefits/added value?

What makes these target groups tick and what do they need (in the future)? What are their needs? What challenges must be overcome for successful exploitation? What needs to be considered?

Developing strategies to achieve exploitation goals and establishing i-Teams
- How can the results be presented?
- What resources are needed to offer results?
- How can the target group be reached? (Communication channels, advantages and disadvantages of different channels...)
- How do the target groups get the results? What networks are needed?

- i-Teams jointly implement the exploitation measures
- Regular coordination and reflection meetings take place
- The sustainability of the exploitation activities beyond the end of the project is ensured

Figure 31: BM Retrofit exploitation process

Responsibilities were clearly allocated within the consortium. The exploitation process was continuously updated and aligned with the technical progress of the project. Target groups for exploitation were systematically identified, including district heating operators, public authorities, planners, technology providers and research organisations. In parallel, a coordinated communication and exploitation roadmap was elaborated to ensure targeted outreach during the project phase. This included the identification and prioritisation of relevant multiplier groups, such as district heating operators, climate and energy model regions (KEM managers), public authorities, sectoral networks and technology providers. Distribution strategies were refined to maximise reach and effectiveness, combining digital dissemination with printed materials such as folded flyers addressed directly to relevant stakeholder groups.

Both scientific and economic exploitation of project results were possible. Scientific exploitation is supported through validated methodologies, system analyses and monitoring results that are transferable to comparable biomass-based district heating systems and have been communicated through scientific conferences and publications. Economic exploitation is enabled through practice-oriented solution approaches, tools and operational concepts that can be adopted by district heating operators, technology providers and planners.

During the project, several exploitable results were consolidated. A central focus was placed on the consolidation of project results and their translation into exploitation-ready formats. In this context, structured fact sheets and brochures were developed for the overall project, the demonstration sites and the key solution approaches (download via the project website). These fact sheets summarise technical, organisational and economic aspects in a standardised format and were finalised in close coordination with the respective partners. They constitute a core exploitation instrument and form the basis for replication and further use by external stakeholders. BM Retrofit successfully established a coherent exploitation framework and transferred the project’s scientific and technical results into exploitable outputs, thereby creating a solid basis for replication, further development and long-term impact beyond the project duration.

Building on the exploitation and dissemination activities, extensive networking activities were established. These activities supported the systematic exchange between project partners, demonstration sites, associated initiatives within the model region, and a broad range of national and international stakeholders. Networking was not treated as a standalone activity but was closely embedded in exploitation planning, dissemination formats and stakeholder-oriented communication measures. Stakeholder and user integration was implemented through targeted networking activities involving public authorities, local administrations and relevant stakeholder groups, including system operators, practitioners and end users.

Collaborations within the Model Region: BM Retrofit directly contributed to the strengthening and expansion of collaborations between subprojects within the designated model region and the affiliated innovation ecosystem. Close cooperation with the Energy Model Region and Green Energy Lab (GEL) was maintained and further deepened, particularly in the context of targeted dissemination formats, joint events and coordinated communication activities. Through these interactions, thematic links were established between BM Retrofit and other innovation projects addressing complementary aspects of the heat transition, including system integration, renewable heat sources and operational optimisation of district heating networks.

Joint workshops, online formats and cross-project exchange within GEL-supported events (e.g. „Highlights aus Forschung und Innovation im Green Energy Lab“) enabled structured knowledge transfer between subprojects and facilitated the alignment of methodological approaches and dissemination strategies. These interactions supported the identification of common challenges, synergies and transferable solutions, particularly with respect to the modernisation of existing energy infrastructures. As a result, collaboration between subprojects evolved from informal exchange towards more structured cooperation, strengthening the innovation capacity of the model region as a whole.

The collaborations established within the model region are expected to generate several additional effects beyond the direct scope of BM Retrofit. These include increased visibility and credibility of retrofit-oriented solutions, accelerated knowledge diffusion among practitioners, and improved coherence between parallel innovation activities. By aligning dissemination and exploitation efforts, the involved projects benefit from a broader reach and more efficient stakeholder engagement, particularly with district heating operators, public authorities and energy planners.

Furthermore, the networking activities contribute to the long-term institutionalisation of cooperation structures within the model region and beyond (e.g. Allianz WärmeZukunft, Austrian Biomass Association). The shared use of dissemination platforms, multiplier networks and communication channels enhances the likelihood that project results will be taken up in follow-up projects, strategic planning processes and implementation activities. In this way, the collaborations initiated through BM Retrofit are expected to support sustained impact and replication beyond the project duration.

National and International Collaborations: In addition to collaborations within the model region, activities fostered extensive cooperation with national and international partners. Dissemination and networking activities were carried out in close interaction with sectoral associations, research organisations, public bodies (e.g. Austrian Biomass Association, Euro Heat and Power) and technology-oriented initiatives (e.g. European Heat Pump Association). These collaborations were strengthened through conference contributions, workshops, newsletters, webinars and targeted communication formats, enabling continuous exchange with relevant stakeholder groups across Austria and Europe.

At the international level, scientific dissemination activities, particularly contributions to conferences such as the European Biomass Conference and Exhibition (EUBCE), the International Conference on Smart Energy Systems and the Central European Biomass Conference (CEBC), created strong links to international research communities, technology developers and policy-oriented networks. These interactions facilitated the positioning of BM Retrofit results in a broader European context and supported exchange on comparable challenges in biomass-based district heating systems.

Overall, the networking activities significantly enhanced collaboration both within the model region and beyond. They supported effective exploitation and dissemination of project results, strengthened cross-project synergies and contributed to the national and international visibility of BM Retrofit. Through the integration of networking into structured exploitation and dissemination processes, the project established a robust foundation for continued cooperation, replication and long-term impact.

6.2 Public and scientific dissemination

Targeted dissemination measures were carried out and various communication channels were used to present the project results achieved and the retrofit and modernisation measures implemented as part of the demonstrators. The main objective of using different communication channels was to reach different target groups (experts, interest groups, communities, citizens, political decision-makers, etc.) at different levels/locations (local, national, and international). The project also emphasises transparent communication with customers, end-users and the public. This is particularly important to establish long-term sustainable cooperation and understanding, which is necessary for a fast heat transition. A key aspect was the development of communication tools and methods for the integration and identification of relevant stakeholders.

The dissemination activities were coordinated with the dissemination activities of the Green Energy Lab and the Climate and Energy Fund, and intensive cooperation and information exchange were implemented. Dissemination activities followed a multi-channel approach, combining public outreach, professional sector communication and scientific dissemination.

Public dissemination included open-door events at demonstration sites Wald im Pinzgau and Hochwolkersdorf, which was attended not only by research partners and heating plant operators but also by members of the public, contributions to local and regional media, newsletters, blogs and special online formats. Further examples include workshops, video contributions and media coverage via ORF Salzburg, social media activities (mainly LinkedIn), blog articles and newsletter features targeting a broader audience interested in sustainable energy solutions. Moreover, display boards containing the most important information on the specific demo measures were created and were placed at the demonstration sites.

A key milestone was the organisation of the first national workshop, which was successfully conducted as an online workshop in February 2025 in cooperation with Green Energy Lab. The program included three presentations followed by a Q&A session. The second national workshop was realised as a dedicated session within the Central European Biomass Conference (CEBC) in January 2026, providing a high-visibility platform for presenting project results to an international expert audience. Both workshops contributed significantly to stakeholder engagement and knowledge transfer. The program was coordinated and aligned with the Austrian Biomass Association and includes a moderated session with five speeches and a panel discussion.

Furthermore, the fact sheets on the key solution approaches were compiled into a brochure, and the solutions were presented to relevant stakeholders in an Online Talk at the beginning of November 2025. A comprehensive stakeholder analysis was carried out for this purpose. In addition, the brochure was sent by post to the identified stakeholders (approx. 550 addresses).

Scientific outputs covered a broad range of topics, including system-level evaluation of retrofit concepts, predictive control strategies, decision-support tools for modernisation measures and the reduction of biomass demand through targeted retrofitting. Scientific dissemination focused on the presentation of validated results at national and international conferences and in professional publications. Several conference papers, oral presentations and posters were accepted, demonstrating the strong scientific output of the project. Contributions were presented at the European Biomass Conference & Exhibition

(EUBCE), International Conference on Smart Energy Systems (SES), the Central European Biomass Conference (CEBC), the International Sustainable Energy Conference and sector-specific events in Austria and Germany (e.g. Mission Innovation Austria, QM-Fachtagung, Österreichische Biomassetag und Heizwerke-Betreibertag, FAST Pichl Seminar „Effiziente Heizwerkführung“, Holzenergie-Tagung Baden-Württemberg , Energiekonferenz Tirol, etc.).

Overall, the performed dissemination activities of BM Retrofit made a substantial contribution to the visibility, transferability and long-term impact of the project outcomes. Key dissemination highlights included the presentation of fully implemented demonstrators, validated system-level retrofit concepts and best practices, including lessons learned. These results were communicated to professional, scientific and public audiences through a mix of public events, sector-specific formats, workshops, webinars and national and international conferences. Online formats played a particularly important role in reaching a wide and diverse audience efficiently. The selected communication channels proved effective in addressing the intended target groups, including district heating operators, planners, researchers, public authorities and other stakeholders. High participation rates, feedback from events and follow-up requests confirmed the successful communication of project results and their practical relevance.

Dissemination activities supported the positioning of BM Retrofit as a reference project for retrofit-oriented approaches in biomass-based district heating systems and stimulated interest in replication and follow-up activities. The close cooperation with Green Energy Lab and the use of established dissemination and multiplier networks were identified as particularly valuable for effective outreach. The use of a diversified set of communication channels proved to be an effective approach for addressing different target groups. In particular, strong visibility was achieved at the demonstrator locations, leading to increased public awareness and local engagement. In addition, dissemination activities stimulated interest from companies and research organisations active in related fields, resulting in new contacts and concrete expressions of interest in knowledge transfer and potential future collaborations.

7 Conclusions and outlook

Within the framework of the project, practice-oriented and transferable solutions for the modernisation of existing biomass-based district heating systems were developed, demonstrated and evaluated. The overarching objective was to adapt existing systems to future technical, economic and environmental requirements through a holistic, system-level approach, thereby significantly increasing efficiency, flexibility and sustainability. A key element of the work package was the derivation of best practices and lessons learned (summarised in Deliverable D7.4) from the different project phases, ranging from problem identification and concept development to implementation, monitoring and optimisation during real operation. For this purpose, the complete work processes at the demonstration sites were systematically documented. This included, in particular, the analysis of organisational and administrative procedures, required permitting processes, legal framework conditions and the applied business models. Furthermore, technical, economic and regulatory bottlenecks were identified and open issues relevant for future projects were highlighted.

The methodological approach developed within BM Retrofit is based on the integrated consideration of technical, organisational and systemic measures. This combination proved essential for the targeted further development of existing district heating networks and for the efficient integration of new technological components into existing infrastructure. The developed concepts were implemented and validated under real operating conditions at three demonstration sites: Wald im Pinzgau, Saalfelden and Kreuzstetten.

At the Wald im Pinzgau site, the focus was on the utilisation of low-temperature waste heat from a nearby hydropower plant by means of a 250 kW heat pump. A power-to-heat unit complemented the system to ensure operational redundancy and by a thermal storage tank with a volume of 30,000 litres to increase system flexibility and to balance load fluctuations.

In Saalfelden, a comprehensive modernisation of the biomass boiler plant was carried out. Key measures included the integration of a cascading heat pump concept into the flue gas condensation process to increase efficiency, the implementation of an innovative control strategy based on CO lambda sensors, the renewal of the flue gas cleaning system, the expansion of thermal storage capacity and the installation of a new supply line to increase the network’s transport capacity.

In Kreuzstetten, the main focus was on targeted network densification based on thermohydraulic simulations, the modernisation and optimisation of boiler and storage control, the reduction of return temperatures through secondary-side measures, and the implementation of a revised operational and business model aimed at improving economic performance.

The results from the demonstration sites clearly show that large-scale retrofit measures in biomass-based district heating systems can be realised within relatively short timeframes, provided that an integrated system perspective is applied. The combination of innovative technologies, data-driven planning tools, predictive control strategies and adapted organisational frameworks enables significant improvements in overall system efficiency and flexibility while simultaneously reducing emissions. At the same time, the optimal use of locally available energy sources is supported, and existing infrastructures can be further developed by exploiting synergies.

Moreover, three complementary solution approaches were developed within the “innovation-teams”, each addressing key leverage points for improving the efficiency, flexibility and sustainability of biomass-based district heating networks

The first solution approach focuses on the optimisation of district heating system operation. It is based on a system-wide perspective that considers heat generation, thermal storage, network infrastructure and control strategies as an integrated whole. By aligning the operation of all system components, inefficiencies resulting from suboptimal interaction can be reduced. This approach supports the efficient use of renewable energy sources and waste heat while enabling flexible operation under changing load conditions and future system extensions.

The second solution approach addresses simulation-based planning and optimisation of district heating networks. Thermohydraulic simulation tools are applied to analyse existing network structures, assess retrofit measures and evaluate options for network expansion or densification. The use of simulation-based methods improves planning reliability, reduces technical and economic risks and enables the comparison of alternative development pathways. This approach supports evidence-based decision-making across different project phases, from concept development to implementation and operation.

The third solution approach targets the enhancement of energy recovery from biomass combustion processes through advanced flue gas condensation combined with heat pump technologies. Low-temperature heat sources are upgraded to usable temperature levels for district heating supply, resulting in increased overall system efficiency and reduced biomass demand. This approach contributes to lower fuel consumption, reduced emissions and improved economic performance, while also increasing the flexibility of heat generation.

Together, these solution approaches form an integrated framework for the modernisation of biomass-based district heating systems. Their combined application enables the systematic improvement of system performance and provides transferable, scalable concepts for the further development of comparable heating networks.

In addition, structured fact sheets were developed for the overall project, the individual demonstration sites and the identified solution approaches. These fact sheets summarise the key technical, organisational and economic characteristics in a standardised format and are available as dedicated dissemination and exploitation materials. They support transparent communication of project results, facilitate knowledge transfer and provide a basis for replication and further implementation by relevant stakeholders.

Overall, the BM Retrofit project demonstrates that holistic modernisation concepts can make a substantial contribution to the transformation of existing district heating systems. The developed model solutions exhibit a high degree of scalability and represent future-oriented reference solutions with strong relevance for national and European applications.

To further advance the heat transition in the district heating sector, additional challenges must be addressed, including integration of large-scale thermal storage and deep geothermal energy, phase-out of large gas-fired CHP plants, and intelligent sector coupling through the use of regional surplus electricity for heating applications. There is also an urgent need to develop new business models and transparent tariff structures to ensure long-term economic sustainability.

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JOANNEUM RESEARCH Forschungsgesellschaft mbH (JR)

Pink GmbH (PNK)

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StepsAhead Energiesysteme GmbH (STEP)

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Figure 32: BM Retrofit project partners